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THE LOSS OF HEAD IN CAST IRON STEEL AND WOOD PIPES AND THE CALIBRATION OF PITOT TUBES

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INTRODUCTION.

The importance of Pitot tubes in determining the velocity of flow of water in conduits, where other means of determining the discharge are impracticable, and in detecting leakage in a large water system, is being realized more and more by the practicing engineer. There have sprung up companies that manufacture Pitot tubes and make observations with them for municipalities and large corporations. These companies guarantee to measure the discharge within a small percentage of correctness. The accuracy of any measurements of discharge by means of a Pitot tube depends upon the calibration of the instrument, by which its coefficient is determined. In order to determine these coefficients accurately, a very large number of observations must be made, and it is important that the tubes be calibrated under conditions as nearly as possible similar to those under which they must be used in actual practice. The most exhaustive investigations made with Pitot tubes of various designs are undoubtedly those by Gardner S. Williams, Clarence W. Hubbell and George H. Fenkell at Detroit, Michigan, in 1898-99, published in Volume 47, Transactions American Society of Civil Engineers. By their very elaborate experiments they showed that a Pitot tube calibrated in still water had a coefficient as much as 10% higher than if calibrated in a 2-in. brass pipe with flowing water.

The laws governing the loss of head in pipes of various materials are not as yet fully determined. The coefficient, c, in Chezy's formula, has been fairly well established for steel and cast iron pipes of various diameters, but is very uncertain for wood pipes, owing to the few experiments made upon this class of pipe. The writers have been unable to find any record of experiments to determine the loss of head in the more common 6-in. and 8-in. bored wood pipes.

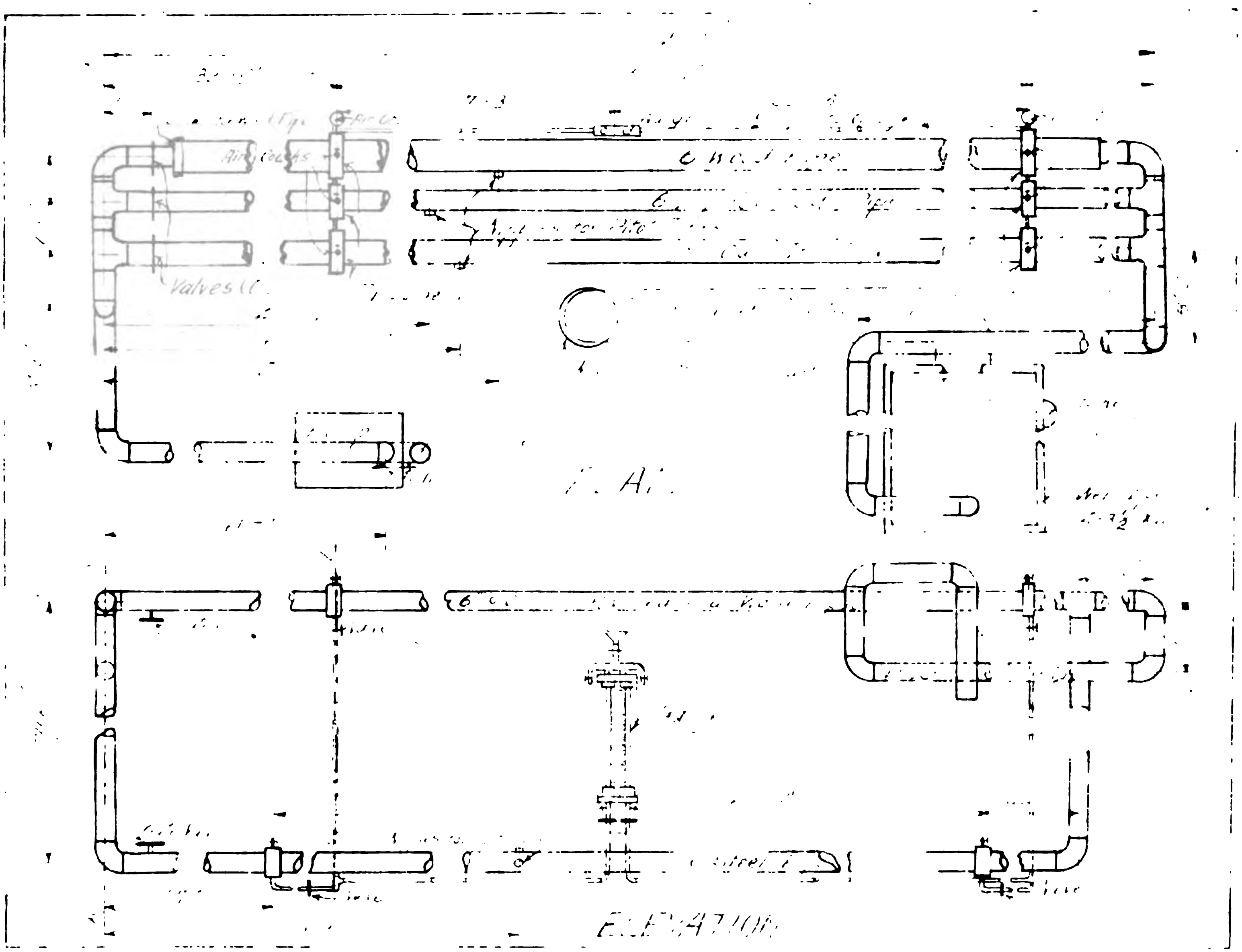
PURPOSE.

The purpose of this investigation was first to determine the loss of head in and coefficients for 6-in. cast iron, wood, steel and lap-riveted pipes, and to determine the variation of loss of head with the velocity. Secondly, the object was to calibrate two Pitot tubes of similar design and to determine the distribution of velocity across the pipes and its relation to curvature in the pipes above the section investigated. For the purpose of the calibration these tubes were tested in all of the four pipes mentioned, and these pipes are of sufficient size to furnish conditions very similar to those existing in large feed mains of 30-in. or even 48-in. diameter.

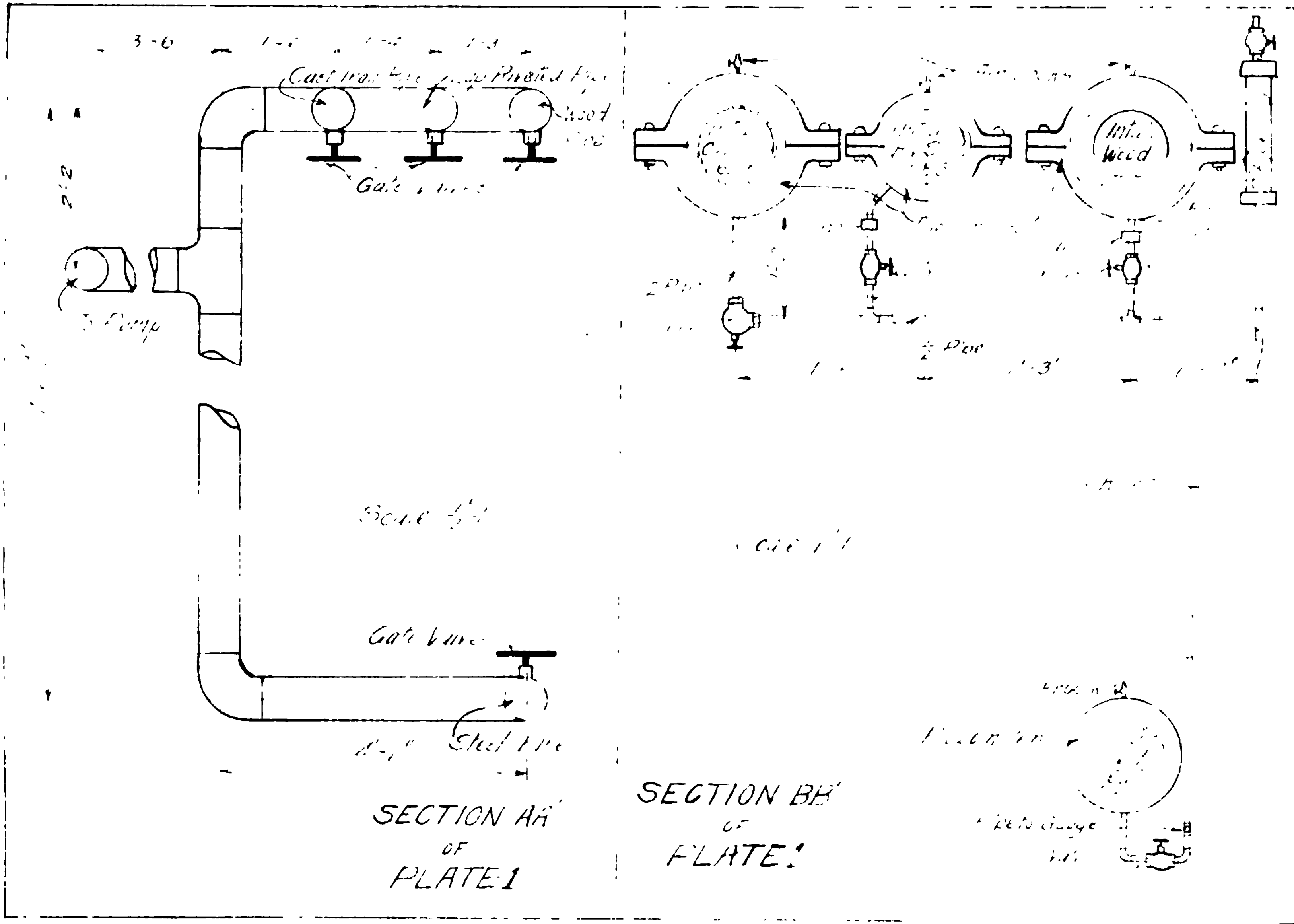
THE PIPES INVESTIGATED.

The four pipe lines experimented upon were all new pipes, that had been installed in the hydraulic laboratory of the University of Wisconsin for the purpose of studying

the laws of flow in pipes of different materials. The pipes had not as yet been utilized, and some trouble was therefore experienced due to leakage in the wood pipe. The plan and elevation of the system of pipes is shown on Plate I. The total straight lengths of the pipes, which extended practically the length of the laboratory, was 95 feet with 90° elbows or tees at each end. The flow through the pipes was controlled by the gates located at the west and intake end. There were no gates at the outlet end. The piezometers were 32 feet 9 inches from the 90° elbow at the upstream end in the case of the wood, lap-riveted and cast iron pipes and 27 feet 9 inches in the case of the steel pipe. The distance between piezometers was 57.02 feet for the steel pipe, 52.75 feet for the wood pipe and 52.83 feet for the cast iron and lap-riveted pipes. The nipples for the Pitot tubes were inserted at cross sections distant from the upstream elbow as follows: in the case of the wood pipe 51 feet 8 inches, the steel pipe 51 feet 11 inches, the cast iron pipe 45 feet 3 inches and the lap-riveted pipe 42 feet 11 inches. These nipples were placed on two diameters 90° apart, and at angles with the horizontal as shown in Plate No. III, Fig. No. II. The piezometer guage was placed 18 feet from the upstream and about 36 feet from the lower piezometers, to which it was connected by 1/2 inch iron piping.



Air cocks
Valves
ELEVATION



SECTION AA' OF PLATE 1

SECTION BB' OF PLATE 1

Water was supplied by a Fairbanks-Morse duplex power pump as shown on Plate No. IV, with a 10 inch stroke and 6 inch plunger, and a rated capacity of 50 revolutions and 245 gallons per minute. Maximum discharge actually secured in our experiments was 348 gallons per minute which gave a velocity of 3.87 feet per second in the cast iron pipe. The suction and discharge pipes were both 5-in., and a by-pass with a regulating valve was connected from the discharge to the suction pipe so that water could be pumped back into the supply chamber and thus low velocities secured. This was found necessary because the minimum power output of the motor did not give low enough velocities. Power was supplied by a variable speed motor on a 500 volt circuit, rated at 46 amperes and 25 H. P. From the pump the water passed through the discharge pipe into the four pipe lines as shown on Plate No. I, making three 90° elbow turns before entering the straight sections of pipe. On leaving the straight sections the water likewise flowed through several 90° elbows with intervening tangents and discharged into a 4 foot 3-1/2 inch by 16 foot 8 inch weir box shown in Plate No. IV. The discharge end of the pipe was a little higher than the three overhead pipes and this gave a suction and discharge head averaging about 12 feet. From the weir box the water flowed over a sharp-crested 12-in. weir with end contractions, and emptied through a discharge pipe back into the supply

chamber. The same water was thus repumped, and the head remained practically constant for every run.

The diameters of the four pipes were obtained by direct measurements with a calibrated iron rod, reading to inches and tenths of an inch. This rod was bent as shown in Plate No. VI, Fig. No. II. It was inserted through the nipple and turned through an angle of 180°, and moved until the knob touched the near side of the pipe and a reading taken. The rod was then pushed to the far side of the pipe and a second reading observed. The difference of the readings plus the width of the knob gave the diameter. Measurements of the diameter could only be obtained at the cross-sections, where the Pitot tubes were inserted and on these two diameters at right angles to one another. Measurements had previously been made of every length of the wood pipe before it was jointed together and layed, and these measurements show a constancy in the diameter, the maximum difference being 1/16 of an inch, which would mean a variation of 1%. The measurements used were taken after the wood pipe had been soaked. The cast iron and steel pipes were all evidently very uniform in cross-section, and the error due to measurement of the diameter is probably not in any case over 1%. The average diameters for the four pipes were as follows: wood 5.92 ins., cast iron 6.06 ins., steel 6.15 ins. and lap-riveted 5.85 ins.

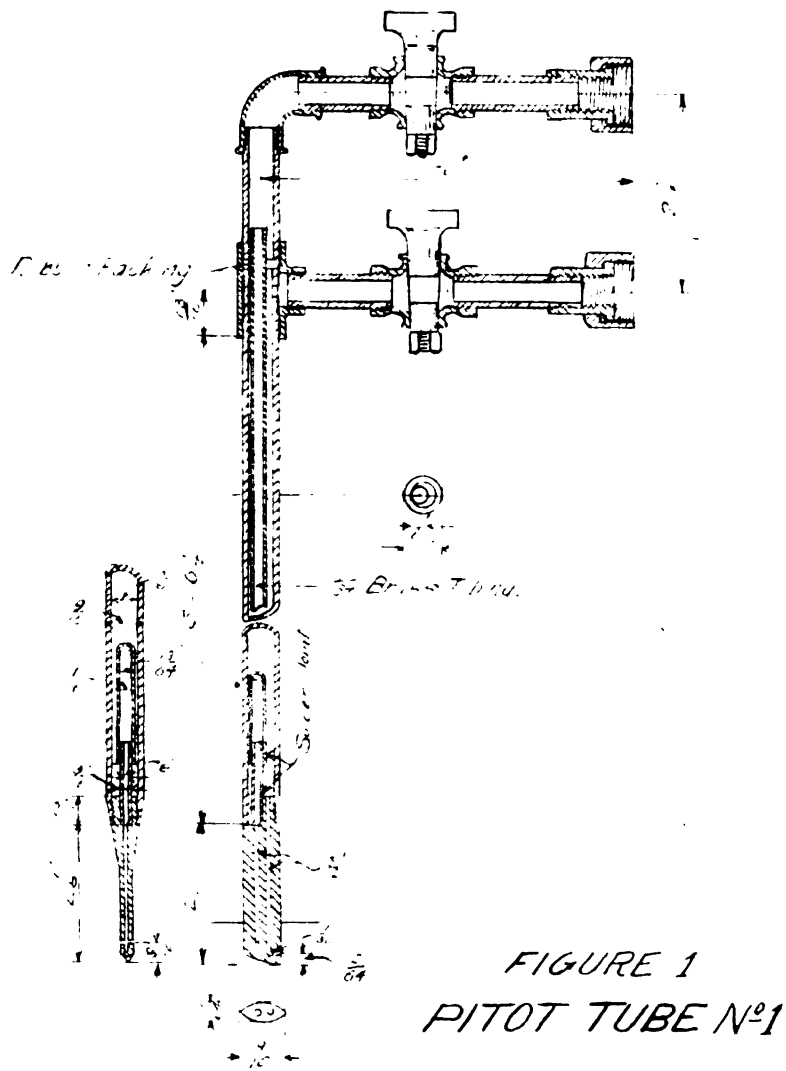


FIGURE 1
PITOT TUBE No.1

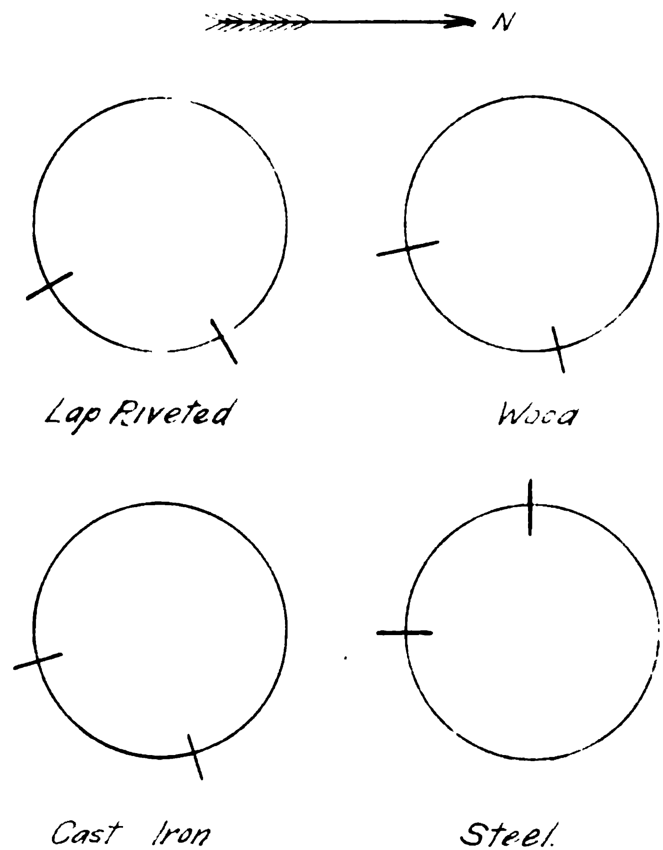
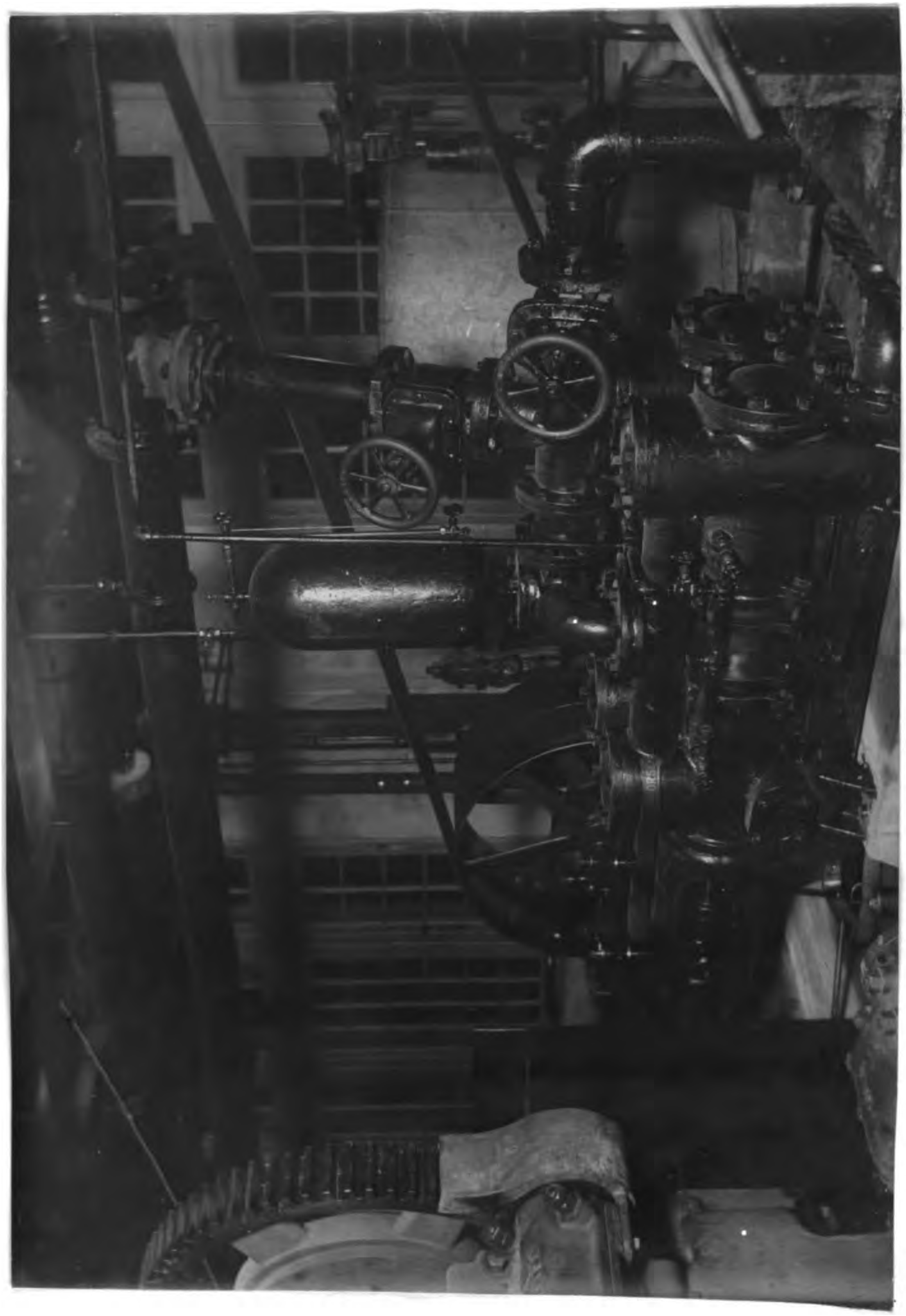


FIGURE 2
LOCATION
OF
NIPPLES FOR PITOT TUBES.

Plate No. 3

The wood pipe was a bored pipe of Douglas fir having a thickness of 2 ins. It was wound outside with 1/8-in. galvanized wire and thoroughly coated with tar. The inside surface was the same as that of a roughly planed board, and not as smooth as the inside of a good wood-stave pipe. Thimble joints were used, thimbles being 1-in. thick and 8-ins. long. Pipe sections were 7-ft. long and there were 7 joints in the section tested by the piezometer guage. The wood pipe caused the chief trouble in leakage, which however was small during the experiments. When water was first passed through the pipe it leaked badly at every joint and especially at the two end joints, where an iron plate had been made to serve as a butt joint connection between the wood pipe and the cast iron elbow fitting. These joints were unadjustable; the pipe had shrunk away from the fixed fitting, and both joints caused endless trouble. They were finally made sufficiently tight for the low pressures used during the experiments in the pipe lines by the use of cement mortar. The thimbles only showed a very slight leakage under high pressures, which were not used however during the experiments. The cast iron pipe is ordinary 6-in. pipe with bell and spigot leaded joints. It is a dipped pipe, presenting a smooth regular surface on the inside. Pipe sections were 12 ft. in length and there are four joints on the section tested by the piezometer guage.

PLATE IV

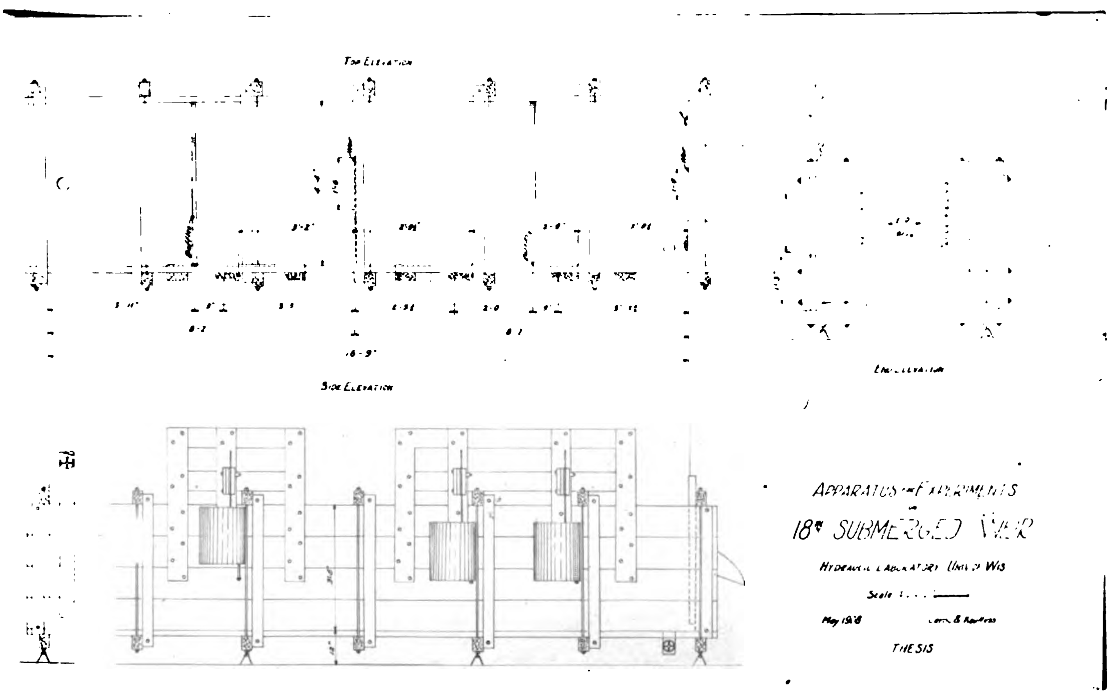


The spiral lap-riveted pipe is a thin, light pipe of 1/16-in. steel. Rivets were spaced 1-in. apart. The pipe was painted with a black preservative paint, which gave a very smooth finished surface. Length along the pipe for one complete turn of the spiral was 1 foot. The steel or wrought iron pipe was a flange jointed pipe .3 in. thick. Pipe sections were 19 ft. long and there were two joints in the portion tested by the piezometer guage. This pipe was not painted on the inside. There was practically no leakage in the cast iron, lap-riveted or steel pipes.

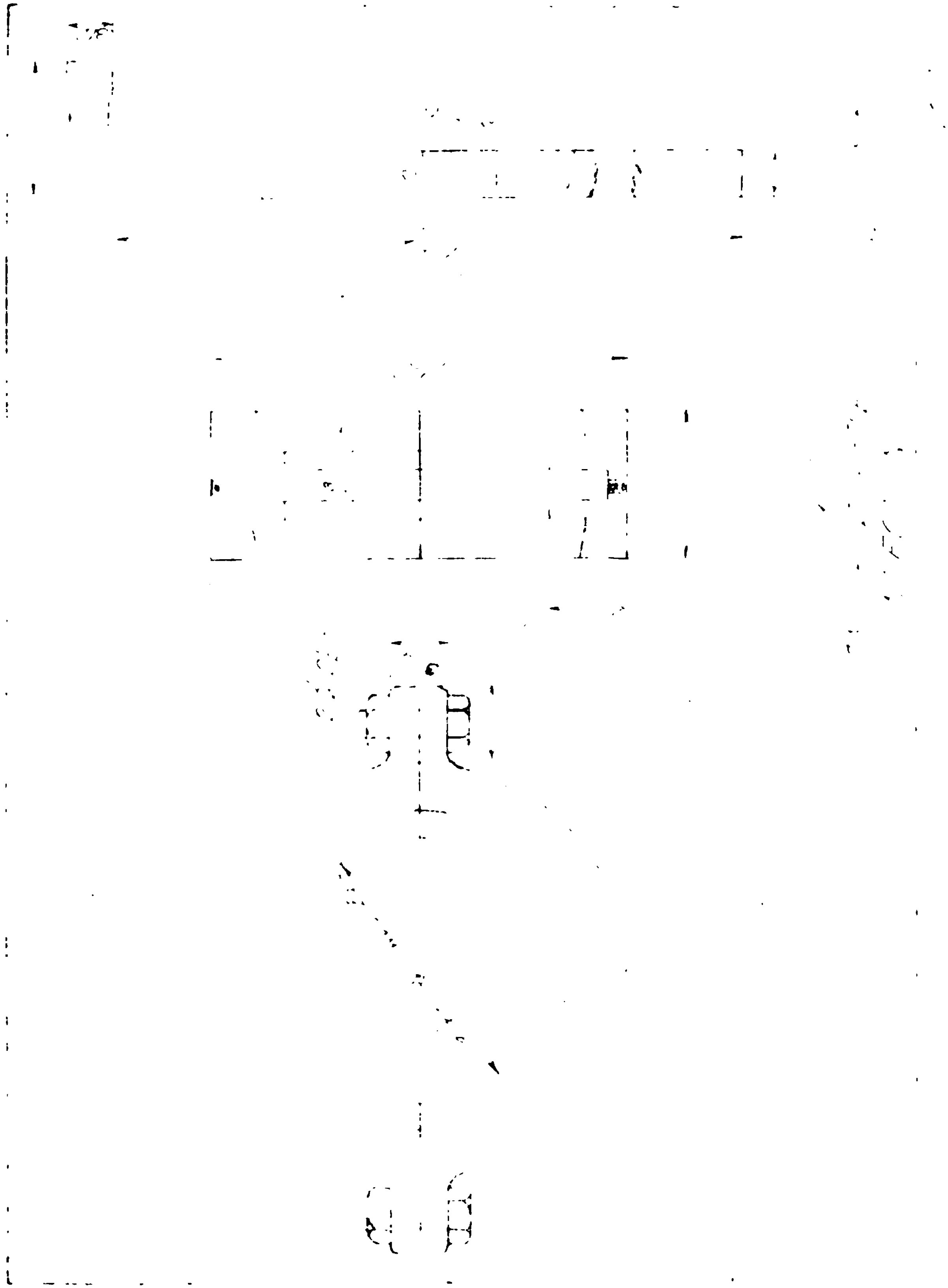
PIEZOMETER CONNECTIONS AND GUAGES.

The piezometer jackets used on the pipes were of the same general design. The channel around the pipe on the inner side of the jacket furnished the necessary equalization of pressure. The form of the jacket is shown on Plate No. VI Fig. No. 1. The piezometers were of different types for the several pipes. In the case of the wood pipe four 1/2-in. holes were bored at an angle of 90° with each other, and making an angle of 45° with the horizontal. These holes were carefully bored at right angles to the line of flow. The auger was withdrawn when the point had pierced the inner side of the pipe, and the hole was then then burned out to full size with a hot iron, so that the inner edge was clean-cut with no projections. The cast iron pipe piezometer was similar to that in the wood pipe except that

PLATE V


Top Elevation
Side Elevation
APPARATUS FOR EXPERIMENTS
18" SUBMERGED WEIR
HYDRAULIC LABORATORY UNIV OF WIS
Scale
THESIS

the holes were 3/8-in. in diameter. The east piezometer of the steel pipe was a fine slit 1/64-in. wide extending entirely around the pipe; the west piezometer was similar with a slit 1/32-in. wide. The piezometer for the spiral lap-riveted pipe was similar to those in the cast iron pipe. The 1/2-in. guage pipes were connected to the under side of the piezometer jackets. The pipes from all jackets were connected to a single 1/2-in. pipe, and the flow through each pipe was controlled by composition metalseated valves placed close to each jacket. Air-cocks were provided in the tops of all piezometer jackets. An air-chamber was placed close to the piezometer connections to collect any air finding its way into the guage pipes, and keep it from getting to the guage. These air-chambers probably were valuable for this purpose; at least no air bubbles were noticed in the guage in the course of the experiments. The piezometer guages used were both of the same pattern, and are shown in Plate No. VII. They were made of 3-ft. glass tubing of 25/32-in. internal diameter, which was connected at the top by 1/2-in. pipe fittings. They were provided with air-cocks both at the top and bottom. Two corporation cocks on the side at the bottom of the right-hand guage were provided to connect the two guages for purpose of calibration without disconnecting this guage from the 1/2-in. pipe. The guage was filled with oil through the 1/4-in.

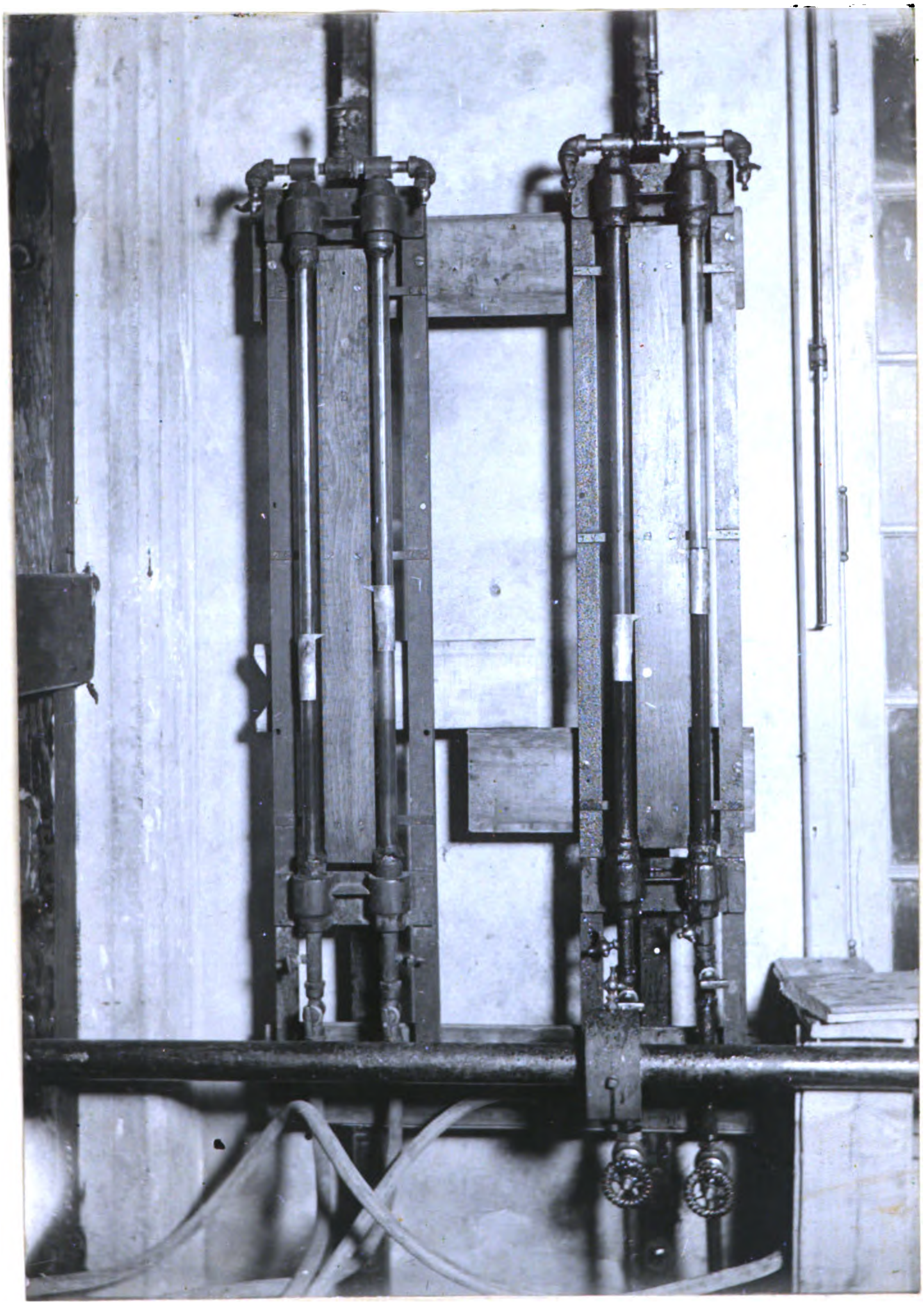


corporation cock at the top, while the water was slowly withdrawn from the air-cock at the bottom. The glass tubes fitted into stuffing boxes and rested upon rubber washers. Over the rubber washers was used cotton packing soaked in common yellow soap. This made a fairly tight connection; there was some trouble with sweating at the joints, but this was remedied by using a stiff composition wax over these places. This wax however is of little account when the guage is under pressure, but it answered well for the low pressures used in these experiments. The greatest trouble in making the guage tight was found in the air-cocks and corporation cocks, many of which could not be made water tight. By trying a number of these and selecting only the best a water-tight guage was secured. Some leaky valves were at once remedied by coating with common yellow soap, which was used in all the valves and connections All valves were tested under a considerable pressure in order to detect leaks. Seat valves of composition metal and also the ordinary air and corporation cocks are very unsatisfactory. Valves with rubber seats should be used in preference to the above types.

PITOT TUBES AND GUAGES

The Pitot tubes tested were identical being made as nearly alike as the mechanician could turn them out. The

PLATE VII



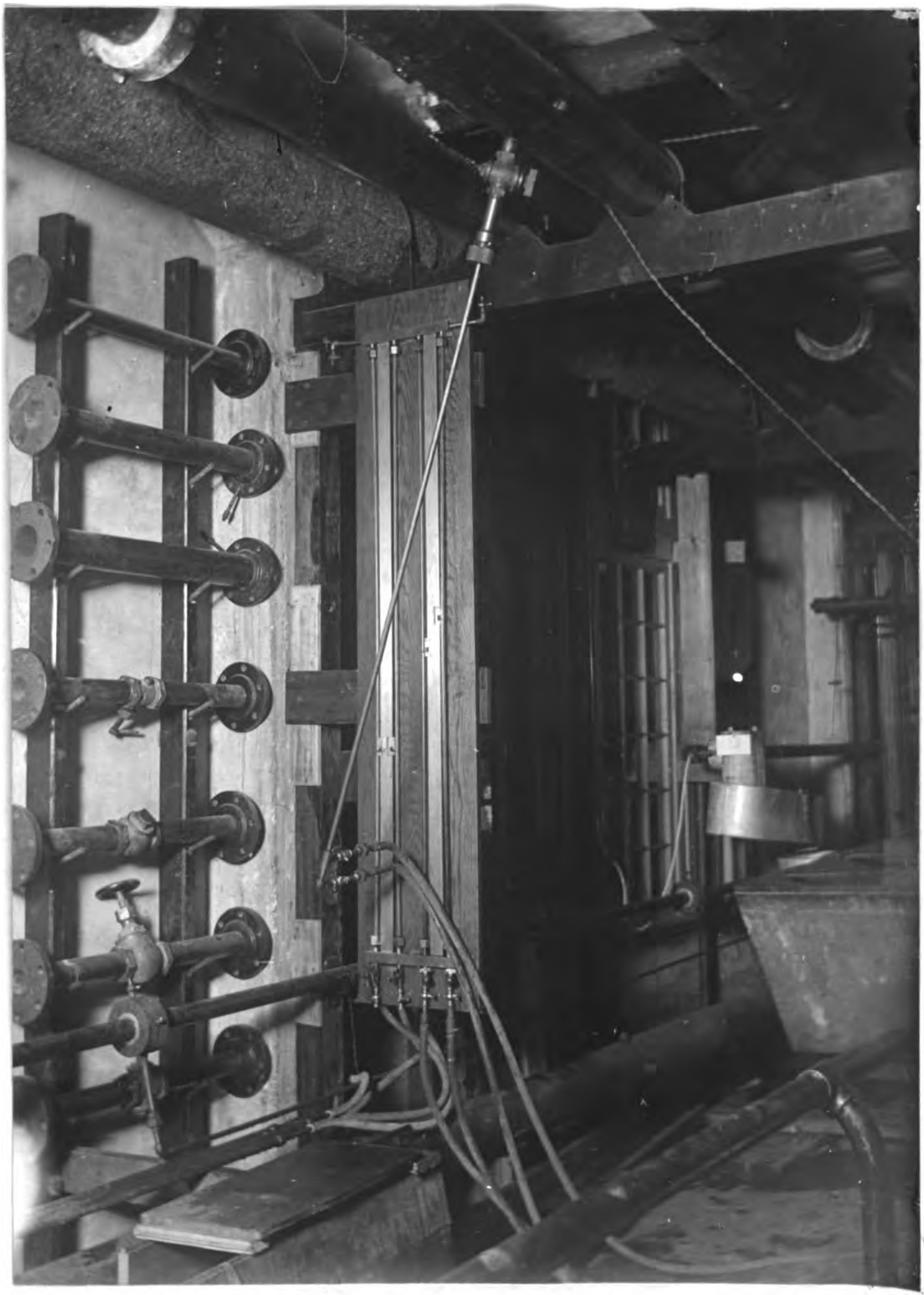
form of the tube is shown in Plate No. III, Fig. No. 1. Both pressure and velocity openings were 1/32 of an inch in diameter. There were two pressure openings and these were connected with a small inside tube which runs the full length of the instrument. The tubes were made 5 ft. 11-5/8 ins. long, in order that they could be used on tests on large feed mains. They were of brass throughout and were made in one piece. Great care was taken in making the impact and pressure openings to drill them exactly at right angles and in line with the plane of the tube tip. The tube arm at the top was made parallel to the line of the velocity opening, and in this way the instrument was aligned with the direction of the pipe.

The method of inserting the Pitot tubes was as follows: 1-in. holes were bored at right angles to the line of the pipe and at angles to the horizontal as shown in Plate No. III, Fig. No. 2. Care was taken to bore the holes at right angles to the line of pipe and along the diameter of the pipe. Different angles with the horizontal were necessary for the several pipes, in order to permit of the insertion of the long Pitot tubes without interference with the pump belt and the side wall of the building. Nipples were then screwed into the pipes, so that the inner end of the nipple was flush with the inner surface of the pipe, the end of the nipple being filed semi-circular for this purpose. A 1-in.

corporation cock was then screwed on the nipple and a stuffing-box long enough to contain all of the tube tip inserted in the cock. The tube is then inserted in the stuffing box and the top nut screwed on the rubber packing which grips the tube. But slight leakage occurred past the stuffing box. The general arrangement of the tube in the pipe can be seen from Plate No. VIII.

For the purpose of observing with the Pitot tube, the pressure and velocity openings of the tube were each connected by a 3/8-in. inside diameter rubber tubing to the two sides of an ordinary air guage. Two of these guages are also shown in Plate No. VIII. The air guage consisted of two parallel glass tubes 5/16 of an inch in diameter fitted with cotton packing soaked in yellow soap into the stuffing boxes of the guage. On each side of the glass tubes is a steel scale graduated to hundredths of a foot with a sliding vernier reading to thousandths. The guage was connected at the top which was filled with air and an air cock was provided to regulate the height of the water column. The difference in the water columns filling the bottom of the guage registered the relative pressures of the velocity and pressure openings. Equal lengths of hose were used on each side and care was taken to expel the air before connecting up.

PLATE VIII



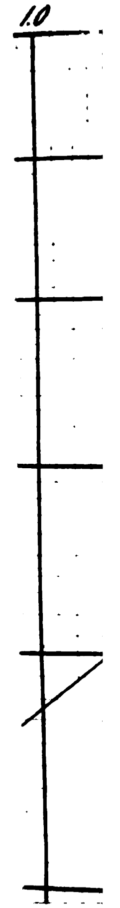
WEIR DISCHARGE.

The velocity of water in the pipes was determined by readings on the 12-in. weir, which were taken every minute during the course of the runs. The head on the weir remained fairly constant during all runs, and the average reading for each velocity gave the correct discharge within a small percentage of correctness. The weir was read by a hook guage, which read by means of a micrometer to one thousandth of a foot. A zero reading was obtained before and after each run, and this reading varied but slightly during the experiment. The method used in getting the water level exactly even with the crest of the weir was that adopted by Messrs. Cerna and Kaulfuss in their thesis on "The Flow of Water over an Eighteen Inch Sharp Crested Rectangular Submerged Weir with End Contractions." By holding an electric light back of and above the weir crest and placing the eye so that the reflection of the light was seen in the water adjacent to the weir crest, the image would assume a convexly flattened appearance if the water edge was convex and a concavely elongated appearance if concave. Water was added to or removed from the weir box until the image appeared in its natural form. Very small additions of water would produce a noticeable change in the image, so that this method is both very accurate and easy of application.

In their experiments Messrs. Cerna and Kaulfuss carefully calibrated this 12-in. weir. The weir discharge curve plotted logarithmically as determined by them is shown in Plate No. IX. All our discharge readings were taken directly from this curve. Plan and elevation of the weir box is shown on Plate No. V.

CALIBRATION OF OIL GUAGES.

In order to reduce the readings of loss of head in the oil guage to water, the differential guages were calibrated in the following manner. One guage was placed about 1-1/2 ft higher than the other, and connected as shown in Plate No. X. The lower guage was partly filled with oil and the remainder of the lower guage, the upper guage, and the connecting hose filled with water. Great care was taken to have no air in either guage or in any of the connections. The top corporation cock of the upper guage was opened and in this condition the columns of oil should stand level. Part of the water in one tube of the upper guage was then drawn out through the small cock at the bottom until D equals at least ± 1 inch, and D and d were observed. Another 1 inch ± of water was then drawn out and D and d again observed, and so on until the difference of the oil columns was greater than could be read by the guage, when in like manner the water in the other column of the upper guage was lowered, until the water now near the bottom of the upper guage again read zero.


1.0

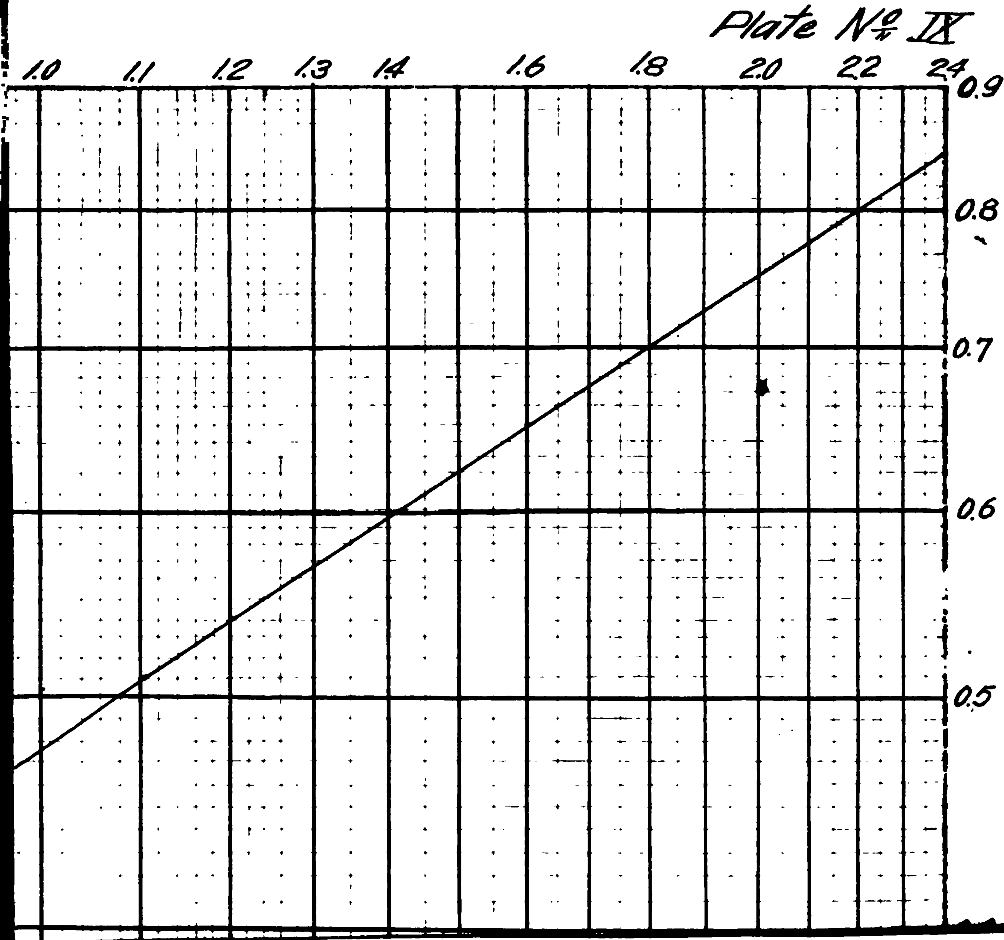


Plate No. IX
1.0
1.1
1.2
1.3
1.4
1.6
1.8
2.0
2.2
2.4
0.9
0.8
0.7
0.6
0.5

The temperature of the water was taken as drawn from the upper guage. Eleven observations were usually made, each setting being read independently by two observers. Six sets of observations were taken for each guage. In averaging the values of $\frac{d}{D}$ readings of D less than 0.17 of a foot were omitted, because they were unreliable on account of inaccuracy in reading these small differences.

The oil used was ordinary kerosene, which gave a ratio of $\frac{d}{D}$ of 5.233 at 16.7° C or 62° F. In reducing the observations correction was not made for the zero reading with the guage full of water, though this was in most all cases negligibly small, since this correction should not enter into the value of $\frac{d}{D}$. It was not possible for the writers, because of lack of time to get a large range of temperature in this calibration, and to determine the effect of temperature upon the ratio $\frac{d}{D}$, so the corrections for temperature were made as follows: In the Detroit experiments Messrs. Williams, Hubbell and Fenkell by a large number of observations determined the effect of temperature upon the value of $\frac{d}{D}$, and they found between 60° and 70° F. that this ratio decreased .0121° C. for every degree C. of increase. This correction was therefore applied to all values of $\frac{d}{D}$ and these reduced to 62° F. or 16.7° C. as given in column No. 5, Table No. 2. In the above mentioned experiments the

value of $\frac{d}{D}$ found was 4.89. Different samples of oil vary in their specific gravity and therefore this ratio is far from constant. After calibration the same oil was used repeatedly in the experiments; after each week's runs the oil was removed from the guage and then replaced on starting the next time.

METHOD OF CONDUCTING EXPERIMENTS.

GENERAL. The Pitot tube and loss of head experiments were conducted simultaneously, and the work of observing was divided between the writers. Perwien read and recorded the weir guage every minute; Schwede read and recorded the piezometer oil guage every minute; and Graff read the Pitot air guage and manipulated the Pitot tube. The pump was operated first at its lowest output, and the by-pass valve opened until the weir reading indicated a velocity in the pipe of 0.5 of a foot per second. For this velocity and also a velocity of one foot per second, the outlet valve was partly closed so that enough pressure was obtained to completely fill the pipe. Observations were made for each velocity from 0.5 feet to 3.5 feet per second, using intervals of .5 feet. The pump maintained a fairly constant velocity throughout each run which required from twenty to thirty minutes, the time depending on the rapidity of the Pitot tube readings. Between each run the pump was regulated

to the next higher velocity and allowed to run some minutes until the weir readings had become constant. A complete set of runs for all velocities was made with the Pitot tube inserted on the horizontal diameter in a pipe and then the operation was repeated with the tube on the vertical diameter. These sets are referred to as, for example, 1 H and 1 V. in the tables, meaning the lowest velocity on the horizontal and vertical diameters respectively.

Manipulation of Piezometer Guages. Before starting a set of experiments the piezometer guage was half filled with oil through the corporation cock at the top by first filling the guage with water and opening the air-cocks to make sure that the guage was free from air, then closing the inlet corporation cocks and slowly drawing out the water through the waste cock at the bottom as the oil was poured in. The inlet corporation cocks were then opened and the guage was ready for use.

The guage was read every minute, twenty readings being taken. There was considerable fluctuation (as much as .07 of a foot) of the oil columns, and the two extreme positions of the columns were read simultaneously, first reading the upper fluctuation and the next time the lower. These two were then averaged and thus ten average readings obtained for each set.

<u>Weir Measurements</u>. Readings of the hook guage were taken every minute. The guage was set in the basin shown in Plate No. V, which was connected with the weir box by a 1-in. pipe, entering at the bottom of the basin. Readings were taken with an electric light. The watches used by the three observers were always set together before commencing any series.

<u>Manipulation of Pitot Tubes</u>. For the higher velocities the pulsation of the water columns in the air guage were quite rapid and of considerable amplitude, as much as .06 ft. in the pressure tube. The vibrations were considerably longer in the pressure column than in the velocity column. For most of the velocities the vibrations were decided and kept time with the strokes of the pump, but in the case of the highest velocity the vibrations were small and irregular because the pressure on the pipe was not sufficient to transmit the pump pulsations through the fine openings of the tube and into the guage. By applying sufficient pressure, the rhythmic vibrations were established in the guage. The readings were taken at the two extremities of the vibrations, and averaged.

Before starting on a series of runs, water was flushed through the air guage and tubing, and then the latter connected with the Pitot tube, so that all air was driven out of the tubes, guage and connections. Air was then let

into the top of the guage, until the water columns stood at a convenient height for reading.

In measuring the discharge of a pipe with a Pitot tube, it is necessary unless it is already known that the velocity distribution is normal and the maximum velocity is at the center, to traverse the diameter of the pipe with the instrument, i. e., to take readings at various points along the diameter. In order to simplify the reductions, the pipe was divided by concentric circles into a central core and a series of rings of equal area, and a reading was taken at the center, at the edge of the pipe as nearly as the tube could approach, and on each intersection of the dividing circles with the diameter. The pipe was divided into five such equal areas, making eleven positions for the tube. At each location the upper and lower extremities of the vibrations were read twice, which occupied one minute, and the tube was then moved to the next position. The first position was the center, then the far side of the pipe was taken and then the points consecutively across the pipe returning to the center at the close. This complete operation constituted a "Traverse." To locate the point of the instrument, an observing rod was used which rested against the top of the stuffing box, and distances set corresponding to the divisions of the diameter of the pipe, by setting a scratch on the tube. Time required for taking the

readings at one position and adjusting the tube for the next location was 1-1/2 minutes. With a man recording as was done for the steel pipe, for which the piezometer readings were taken separately the time was one minute.

A number of readings were taken at no flow, and in most cases the guage did not read zero but read positively about .005 ft. Correction was made for the no flow reading in all the reductions. The velocity tube of the guage was for the majority of the experiments the right-hand one. For one run the left-hand tube was connected to the velocity opening, and a large difference in the no flow reading was observed, as it dropped to -0.019 ft. This may show that the condition of the parts of the guage connections affect the zero reading.

TABULATION AND REDUCTION OF DATA.

All data taken during the experiments are on file at the hydraulic laboratory of the University of Wisconsin, and comprise 131 pages of tabulation of which 10 pages are summary tables. Only the latter and a portion of every table are printed in this copy; this data will hereafter be referred to as "Laboratory Data." All the reductions from this data were checked. The usual method followed was for one of the writers to check the other's work.

<u>Calibration of Oil Guages</u>. On pages 21 to 22 are given

three typical sets of Table No. 1, Laboratory Data pages 1 to 7. Column No. 11 was obtained by dividing column No. 8 by column No.5. The temperature was obtained from the water taken from the upper or water guage. Sets Nos. 1 to 6 inclusive were taken with Guage No. 1 as the water guage, and for sets Nos. 7 to 12 inclusive Guage No. 2 was lowered below Guage No. 1 and the latter was the the kerosene guage.

In Table No. 2 is given a summary of Table No.1. In column No.4 is given the correction to be applied to reduce $\frac{d}{D}$ to 16.7° C. This correction was obtained as explained on page No. 14 and is -.0121° for +1°C. In column No.5 is given the corrected $\frac{d}{D}$.

<u>Weir Discharge</u>. The weir readings and averages for each traverse are given on pages 39 to 64 inclusive, Laboratory Data. These averages are inserted in Table No.4 and also the weir discharge which was obtained from Plate No. 9. In Table No.5 are given the measurements of pipe diameters and also the lengths of pipes between piezometers.

<u>Piezometers</u>. One typical set of the piezometer data from each of the pipes as tabulated in Table No. 3, (a), (b), (c) and (d), Laboratory Data, pages Nos. 9 to 38 inclusive, is given on pages Nos. 25 to 28 inclusive. Column No. 5 gives the average of the readings of the upper and lower

Table No. 1.

Calibration of Differential Oil Gauges. Set No. 1. Apr.4,1908.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
		Gauge No. 1 Water			Gauge No. 2 Kerosene				d/D for each obs.
Time	Obser-ver	Left	Right	Difference	Left	Right	Difference	Temp. Cent.	
3:02	S	1.682	1.537	0.145	1.850	1.095	0.755		5.20
	G	1.682	1.538	0.144	1.850	1.097	0.753	17.55	5.24
3:04	S	1.606	1.436	0.170	1.921	1.025	0.896		5.27
	G	1.607	1.437	0.170	1.922	1.026	0.896	17.5	5.27
3:07	S	1.534	1.337	0.197	1,994	0.956	1.038		5.21
	G	1.536	1.337	0.199	1.994	0.955	1.039		5.27
3:11	S	1.465	1.242	0.223	2.061	0.891	1.170	17.4	5.24
	G	1.464	1.242	0.222	2.060	0.891	1.169		5.27
3:16	S	1.407	1.158	0.249	2.119	0.832	1.287	17.8	5.16
	G	1.407	1.158	0.249	2.118	0.832	1.286		5.16
3:21	S	1.334	1.061	0.273	2.189	0.763	1.426	17.8	5.23
	G	1.332	1.061	0.271	2.189	0.761	1.428		5.26
3:25	S	1.235	0.926	0.309	2.282	0.669	1.613	17.8	5.22
	G	1.237	0.927	0.310	2.284	0.670	1.614		5.21
3:29	S	1.143	0.798	0.345	2.371	0.577	1.794	17.7	5.20
	G	1.142	0.798	0.344	2.370	0.577	1.793		5.22
3:34	S	1.024	0.639	0.385	2.483	0.464	2.019	17.8	5.21
	G	1.027	0.639	0.388	2.486	0.465	2.021		5.25
3:37	S	0.807	0.478	0.329	2.334	0.613	1.721	17.8	5.26
	G	0.806	0.479	0.327	2.334	0.613	1.721		5.24
3:42	S	0.622	0.344	0.278	2.207	0.741	1.466	17.9	5.27
	G	0.624	0.340	0.284	2.208	0.742	1.466		5.16
4:02								20.9	
									5.23

Table No. 1 Continued.

Calibration of Differential Oil gauge. Set No. 2. Apr.10,1908.

(1) T	(2) O	(3) L	(4) R	(5) D	(6) L	(7) R	(8) D	(9) Temp.	(10) d/D
4:25	G	Gauge Full of Water			1.503	1.500	0.003	17.65	
	S				1.502	1.501	0.001		
5:05	G	2.372	2.370	0.002	1.560	1.546	0.014	17.45	7.00
	S	2.374	2.372	0.002	1.562	1.547	0.015		7.50
5:12	G	1.947	2.062	0.115	1.260	1.840	0.580	19.30	5.05
	S	1.947	2.062	0.115	1.260	1.841	0.581		5.05
5:17	G	1.635	1.831	0.196	1.037	2.053	1.016	21.30	5.18
	S	1.635	1.832	0.197	1.038	2.052	1.014		5.17
5.22	G	1.309	1.591	0.282	0.810	2.274	1.464	20.1	5.19
	S	1.312	1.594	0.282	0.813	2.278	1.465		5.19
5:27	G	0.961	1.336	0.375	0.570	2.510	1.940	20.4	5.17
	S	0.962	1.336	0.374	0.570	2.508	1.938		5.19
5:32	G	0.748	1.043	0.295	0.774	2.311	1.537	20.5	5.20
	S	0.747	1.042	0.295	0.775	2.313	1.538		5.21
5:37	G	0.598	0.838	0.240	0.918	2.171	1.253	20.8	5.24
	S	0.596	0.837	0.239	0.919	2.172	1.253		5.22
5:39	G	0.424	0.603	0.179	1.085	2.011	0.926		5.19
	S	0.425	0.603	0.180	1.085	2.013	0.928		5.15
5:43	G	0.183	0.272	0.089	1.318	1.784	0.466		5.23
	S	0.183	0.274	0.091	1.319	1.784	0.465		5.12

Set No. 3. Apr.17,1908.

(1) T	(2) O	(3) L	(4) R	(5) D	(6) L	(7) R	(8) D	(9) Temp.	(10) d/D
9:45	G	Gauge full of Water			1.396	1.396			
	P				1.397	1.397	0.000		
9:50	G	2.272	2.412	0.140	1.026	1.756	0.730		5.21
	P	2.273	2.412	0.139	1.027	1.757	0.730	19.9	5.25
9:55	G	1.937	2.170	0.233	0.787	1.990	1.203		5.16
	P	1.940	2.170	0.230	0.786	1.988	1.202	19.9	5.23
10:02	G	1.685	1.987	0.302	0.610	2.163	1.553		5.14
	P	1.686	1.986	0.300	0.609	2.161	1.552	19.92	5.18
10:10	G	1.381	1.763	0.382	0.396	2.370	1.974		5.17
	P	1.382	1.761	0.379	0.397	2.370	1.973	19.9	5.21
10:15	G	1.127	1.572	0.445	0.217	2.539	2.322		5.21
	P	1.129	1.574	0.445	0.220	2.539	2.319	19.8	5.22
10:20	G	0.926	1.301	0.375	0.405	2.356	1.951		5.20
	P	0.927	1.300	0.373	0.409	2.358	1.949	19.9	5.23
10:30	G	0.754	1.068	0.314	0.577	2.201	1.624	1	5.17
	P	0.755	1.069	0.314	0.575	2.200	1.625	20.0	5.17
10:35	G	0.521	0.746	0.225	0.800	1.980	1.180		5.22
	P	0.520	0.746	0.226	0.801	1.980	1.179	20.0	5.24
10:40	G	0.316	0.467	0.151	0.998	1.788	0.790		5.22
	P	0.315	0.468	0.153	1.001	1.789	0.788	20.4	5.17
10:45	G	0.096	0.166	0.070	1.210	1.582	0.372		5.31
	P	0.098	0.167	0.069	1.208	1.581	0.373		5.40

Table No. 2.

Summary of Oil Gauge Calibration.

No. of Set.	Av. d/D.	Temp. C.	Cor. to 16.7 C.	Cor. d/D.	No. of Ker. Gauge.
(1).	(2).	(3).	(4).	(5).	(6).
1	5.23	17.7°	+.0121	5.24	2
2	5.19	20.6°	+.0472	5.24	2
3	5.20	19.9°	+.0388	5.24	2
4	5.18	20.6°	+.0472	5.23	2
5	5.14	20.6°	+.0472	5.19	2
6	5.17	20.95°	+.0515	5.22	2
7	5.27	18.38°	+.0203	5.29	1
8	5.24	19.19°	+.0301	5.27	1
9	5.25	17.66°	+.0116	5.26	1
10	5.20	17.26°	+.0068	5.21	1
11	5.18	18.16°	+.01765	5.20	1
12	5.19	19.23°	+.0306	5.22	1

Note:- Correction to d/D for +1° C -.0121

Average for Gauge 2 at 16.7°C 5.227

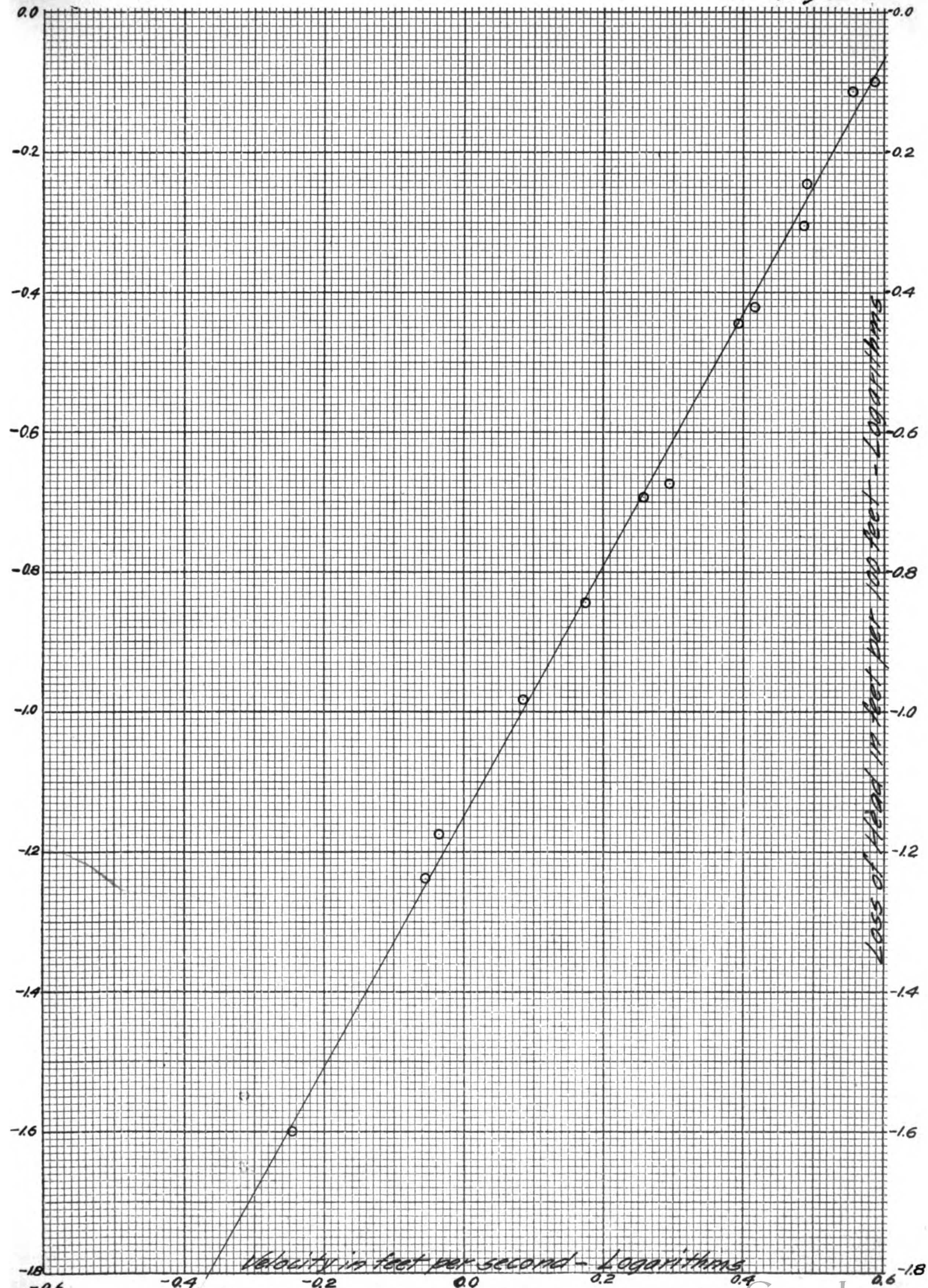
Average for Gauge 1 at 16.7°C 5.24

Final Average at 16.7°C 5.233

extremities of the vibrations. In column No. 6 is given the weir readings and the average of these readings for each run. The temperature of the water was read in the weir box, and the guage temperature by tapping water from the guage between runs. These temperatures are given at the top of each set.

In Table No. 4, (a), (b), (c) and (d), is given a summary of Table No. 3, (a), (b), (c) and (d) for the cast iron, wood, steel and lap-riveted pipes respectively. In column No. 3 is given the average difference for each set as read by the kerosene guage. In column No.6 is given the kerosene coefficient corrected to the guage temperature as given in column No.5, by applying the correction of -.0121 for each degree Centigrade above 16.7° C. In column No.7 the loss of head in kerosene is reduced to its equivalent in water for a 100-ft. length of pipe. The true mean velocities, V_w, as determined by the weir are calculated from the diameter of the pipe and given in column No.11.

Figures Nos. 1 to 4 inclusive are plotted from the values of the logs. of H_f and V_w, given in columns Nos. 8 and 11. The logarithmic curves thus obtained were found to be straight lines. The straight line curves shown on these figures were drawn by the center of gravity method as



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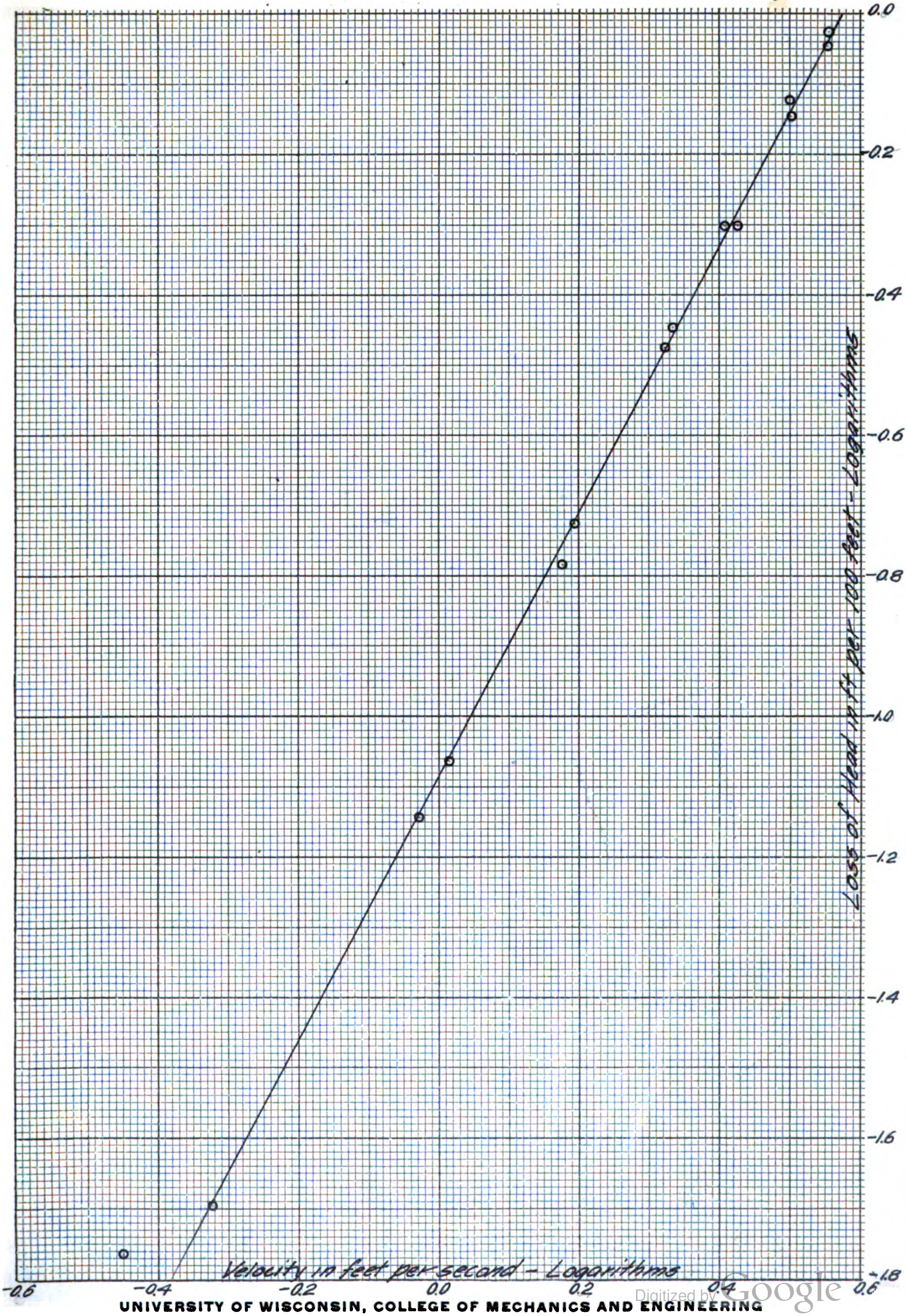
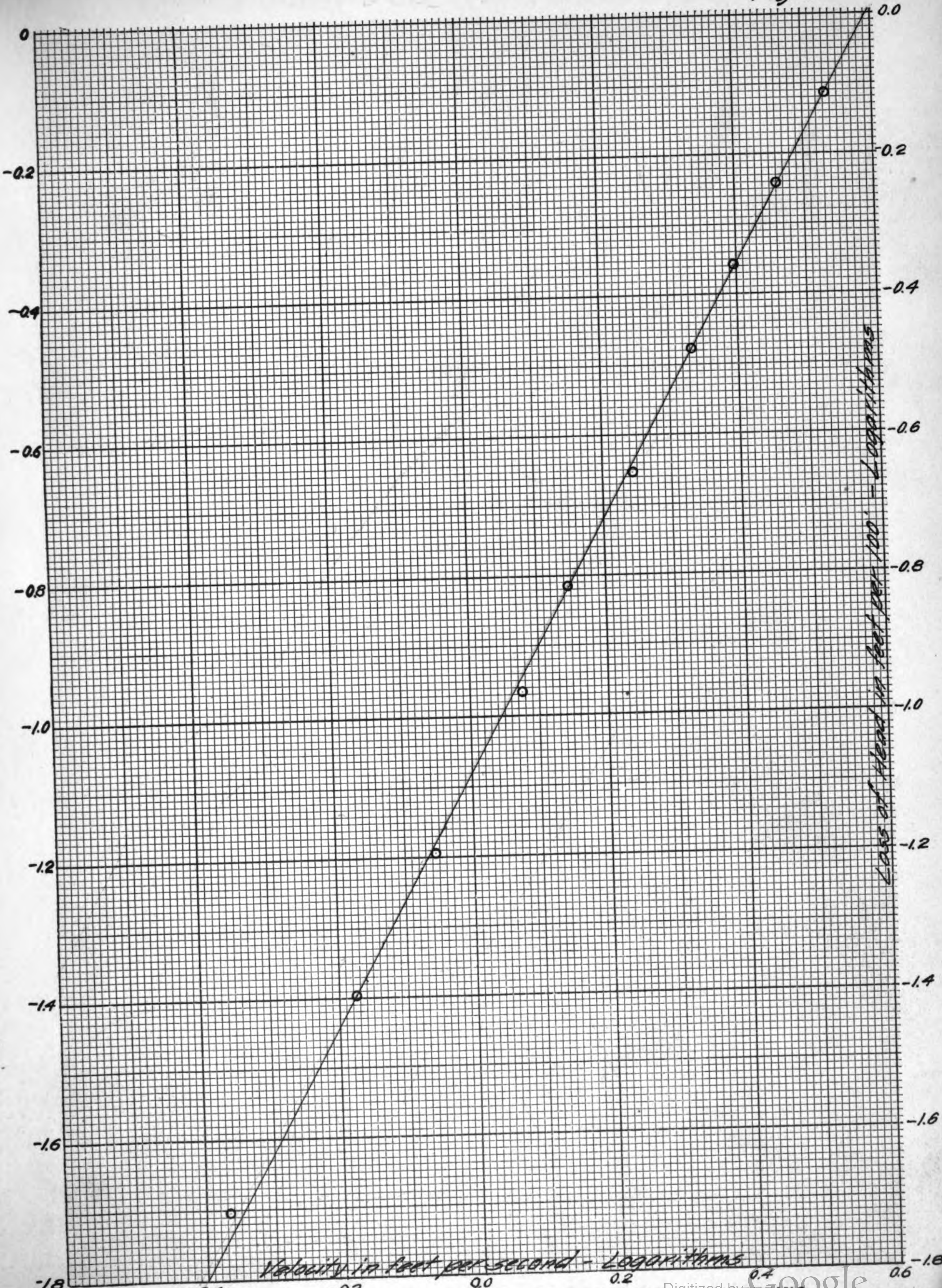
LOSS OF HEAD IN 6" CAST-IRON PIPE

Fig 2



UNIVERSITY OF WISCONSIN, COLLEGE OF MECHANICS AND ENGINEERING

LOSS OF HEAD IN 6-INCH WOOD PIPE



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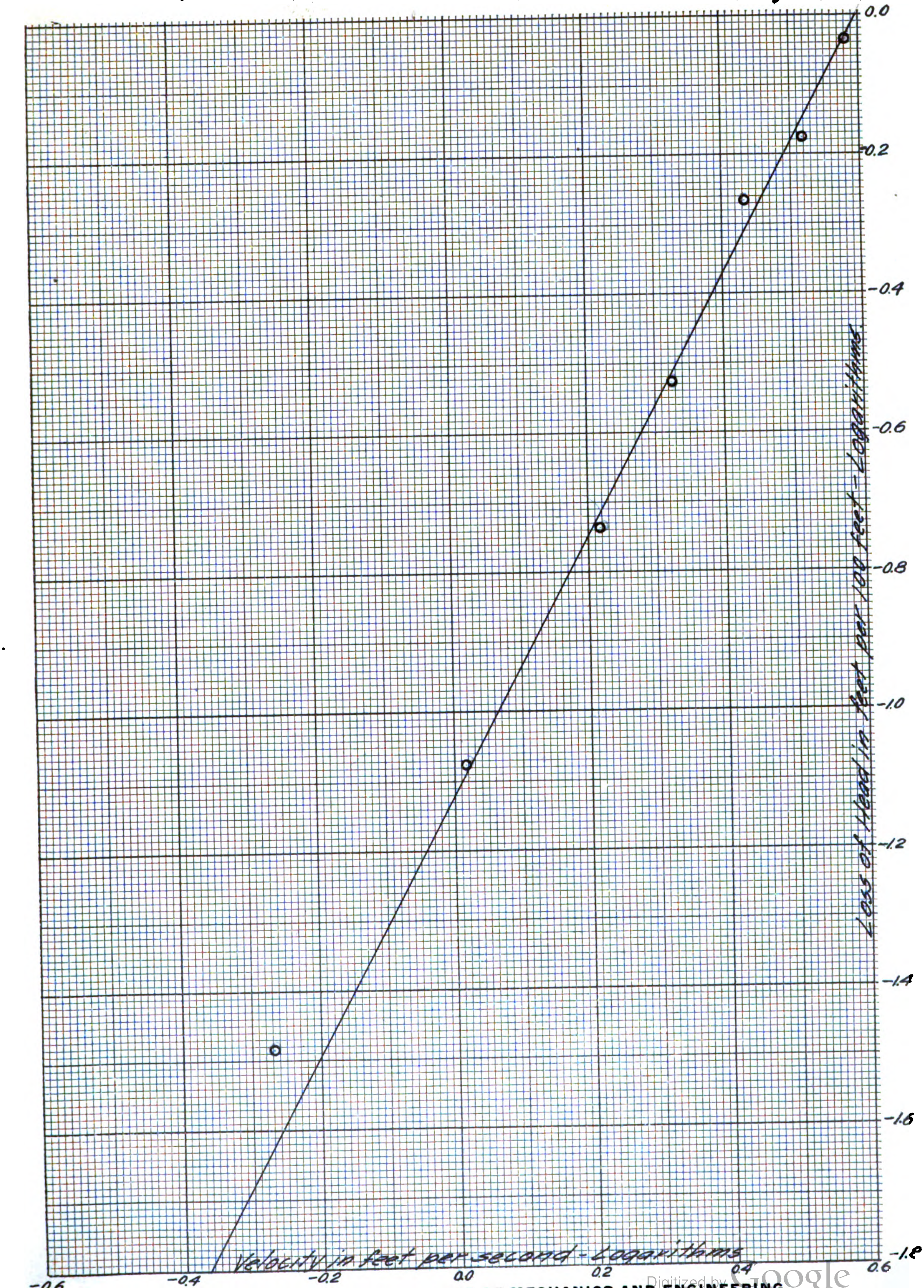
LOSS OF HEAD IN 6-INCH STEEL PIPE

Fig. 4.



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LOSS OF HEAD IN 6" SPIRAL LAP-RIVETED PIPE

Table No. 3 (a).

Loss of Head in 6" Cast Iron Pipe.

Data by F.A.Schwede and R.Perwien.

SET VII.

1 No. of Observation.	2 Time. 5/1/08.	3 Piezometer Gauge No.2 L.	4 R.	5 Difference in feet. Kerosene. D.	6 Head on Wier. ft. Hw.
	P.M.				
1	2:44	1.730	1.115		.2322
2	2:45	1.700	1.138	.588	.2332
3	2:46	1.710	1.140		.2314
4	2:47	1.694	1.149	.558	.2321
5	2:48	1.714	1.130		.2322
6	2:49	1.697	1.144	.562	.2317
7	2:50	1.713	1.135		.2302
8	2:51	1.687	1.153	.556	.2326
9	2:52	1.722	1.128		.2336
10	2:53	1.690	1.150	.567	.2314
11	2:54	1.705	1.138		.2325
12	2:55	1.678	1.160	.542	.2321
13	2:56	1.706	1.139		.2311
14	2:57	1.683	1.162	.544	.2314
15	2:48	1.712	1.134		.2308
16	2:59	1.684	1.153	.554	.2317
17	3:00	1.710	1.135		.2306
18	3:01	1.697	1.144	.559	.2317
19	3:02	1.720	1.130		.2312
20	3:03	1.690	1.156	.562	.2311
			Av.	.559	.2317

Temp. of Water 14.0 C.

Gauge Temp. 16.6 C.

Table No. 3 (b).

Loss of Head in 6" Wood Pipe.

Set IV.(V)

1	2	3	4	5	6
	P.M.				
1	10:12	1.863	.894		.2504
2	10:13	1.860	.895	0.967	.2525
3	10:14	1.873	.882		.2533
4	10:15	1:863	.893	0.980	.2530
5	10:16	1.866	.889		.2525
6	10:17	1.872	.885	0.982	.2509
7	10:18	1.886	.872		.2516
8	10:19	1.875	.888	1.000	.2523
9	10:20	1.886	.875		.2525
10	10:21	1.874	.890	0.998	.2523
11	10:22	1.890	.872		.2520
12	10:23	1.871	.895	0.997	.2515
13	10:24	1.893	.873		.2521
14	10:25	1.877	.891	1.003	.2519
15	10:26	1.895	.877		.2524
16	10:27	1.874	.897	0.998	.2531
17	10:28	1.887	.887		.2536
18	10:29	1.880	.896	0.997	.2523
19	10:30	1.894	.882		.2534
20	10:31	1.870	.904	0.989	.2533
			Av.	0.9911	.2523

Temp. of Water 12.1 C.

Gauge Temp. 13.0 C.

Table No. 3 (c)

Loss of Head in 6" Steel Pipe

Set VI.

1	2	3	4	5	6.
	P.M.				
1	10:42	1.690	1.012		.2311
2	10:43	1.672	1.027	.661	.2314
3	10:44	1.693	1.008		.2315
4	10:45	1.670	1.027	.664	.2314
5	10:46	1.691	1.010		.2312
6	10:47	1.671	1.029	.662	.2310
7	10:48	1.691	1.012		.2309
8	10:49	1.680	1.022	.669	.2313
9	10:50	1.685	1.015		.2312
10	10:51	1.672	1.027	.658	.2313
11	10:52	1.687	1.018		.2314
12	10:53	1.680	1.022	.664	.2316
13	10:54	1.691	1.014		.2314
14	10:55	1.675	1.023	.663	.2316
15	10:56	1.694	1.010		.2318
16	10:57	1.675	1.025	.667	.2315
17	10:58	1.691	1.011		.2318
18	10:59	1.681	1.025	.668	.2319
19	11:00	1.691	1.011		.2316
20	11:01	1.677	1.027	.665	.2316
			Av.	.6641	.2314

Temp. of Water 14.2 C

Gauge Temp. 16.7 C.

Table No. 3 (d).

Loss of Head in 6" Lap-Riveted Pipe.

Set IV. (V)

1		2	3	4	5	6.
	5/8/8	P.M.				
1		9:15	1.763	.943		.2439
2		9:16	1.743	.963	.800	.2446
3		9:17	1.740	.964		.2443
4		9:18	1.730	.976	.765	.2453
5		9:19	1.742	.965		.2453
6		9:20	1.745	.958	.782	.2468
7		9:21	1.760	.947		.2454
8		9:22	1.757	.951	.810	.2452
9		9:23	1.759	.947		.2448
10		9:24	1.759	.948	.812	.2438
11		9:25	1.767	.939		.2440
12		9:26	1.768	.940	.828	.2453
13		9:27	1.771	.935		.2457
14		9:28	1.770	.936	.835	.2467
15		9:29	1.774	.933		.2459
16		9:30	1.772	.935	.838	.2472
17		9:31	1.780	.929		.2477
18		9:32	1.774	.932	.846	.2470
19		9:33	1.775	.934		.2461
20		9:34	1.772	.936	.838	.2469
					Av. .8154	Av. .2456

Temp. of Water 12.4 C.

Gauge Temp. 18.4 C.

Table No. 5.

Pipe Measurements.

Inside Dia. Wood Pipe.

Ob.		Near	Far.	Diff.	Diam.
G.	1Hw	3.58	9.24	5.66	5.97
	2He	3.58	9.17	5.59	5.90
	1Vw	3.30	9.02	5.72	6.03
	2Ve	3.36	9.03	5.67	5.98
S.	1Hw	3.64	9.22	5.58	5.89
	2He	3.70	9.17	5.47	5.78
	1Vw	3.42	9.98	5.56	5.87
	2Ve	3.36	9.02	5.66	5.97
P.	1Hw	3.58	9.18	5.60	5.91
	2He	3.64	9.17	5.53	5.84
	1Vw	3.38	9.03	5.65	5.96
	2Ve	3.39	9.03	5.64	5.95
				Av.	5.92
				Area	.1911

Inside Dia. Steel Pipe.

Ob.		Near	Far	Diff.	Diam.
G.	Hw	1.80	7.66	5.86	6.17
	He	1.76	7.62	5.86	6.17
	Vw	1.81	7.67	5.86	6.17
	Ve	1.87	7.66	5.81	6.12
S	Hw	1.82	7.69	5.87	6.18
	He	1.81	7.62	5.81	6.12
	Vw	1.88	7.70	5.82	6.13
	Ve	1.86	7.65	5.79	6.10
				Av.	6.15
				Area	.2063

Inside Dia. Lap R. Pipe.

G.	Hw			
	He			
	Vw			
	Ve			
P.	Hw	3.00	8.49	5.80
	He	2.97	8.50	5.84
	Vw	3.18	8.70	5.90
	Ve	3.14	8.75	5.92
S.	Hw	3.00	8.48	5.79
	He	2.97	8.50	5.84
	Vw	3.16	8.72	5.87
	Ve	3.20	8.74	5.85
			Av.	5.85
			Area	.1868

Dia. C.I. Pipe 6.06".

Ob.	Hor. Meas.	Vert. Meas.	Av.
G.	6.02	6.03	6.025
	6.06	6.04	6.05
P.	6.05	6.07	6.06
	6.05	6.06	6.055
S.	6.06	6.08	6.08
	6.03	6.13	6.06
	Total Av.		6.06

Area .2003.

Length of Pipe Between Pizometers. Ft.

Pipe		
	Cast Iron	52.83
	Wood	52.75
	Steel	57.02
	Lap Riveted.	52.83

Table No. 4 (a)

Loss of Head in 6" Cast Iron Pipe.

1. Date and Time.	2. No. of set.	3. Gauge #2 (Kerosene) Av. Dif. ft. for 52.83'	4. Temp. of Water	5. Gauge Temp.	6. Kerosene Coef.	7. Loss of head ft per 100' pipe	8. Log Hf	9. Av. Head on Wier ft.	10. Av. Dis. Cu. ft/s.	11. Mean Vel. from Wier ft/s.	12. Log Vm.
T.	No.	Dm.	C.	C.	c.	Hf.		Vw.	Q.	Vm	
5/1/08 4:52PM	1	.0358	14.0	16.7	5.233	.0130	-1.886	.0716	0.656	0.328	-.484
5/1/08 5:24PM	2	.0696	14.0	16.7	5.233	.0252	-1.599	.1044	.1137	.568	-.246
5/15 10:57AM	1v	.0778	14.4	17.4	5.225	.0282	-1.550	.0937	.0968	0.484	-.315
4/30 10:[illegible]0PM	3	.1280	13.9	15.0	5.254	.0461	-1.336	.1133	.1279	0.639	-.194
5/1 4:06PM	4	.1591	14.0	16.6	5.234	.0577	-1.239	.1406	.1765	0.882	.054
5/15 11:23AM	2v	.1847	14.4	17.4	5.225	.0670	-1.174	.1450	.1839	0.920	.036
4/30 9:34PM	5	.2892	13.9	15.0	5.254	.1042	-0.982	.1760	.2435	1.217	.085
5/15 2:30PM	3v	.3318	14.4	17.8	5.220	.1203	-0.920	.1998	.2928	1.464	.166
5/1 12:10PM	6	.3964	14.0	16.7	5.233	.1437	-0.843	.2026	.2990	1.495	.175
5/1 2:44PM	7	.5592	14.0	16.6	5.234	.2024	-0.694	.2317	.3625	1.812	.258
5/15 2:58PM	4v	.5825	14.4	17.8	5.220	.2115	-0.675	.2460	.3945	1.972	.295
5/1/08 10:39AM	8	.9924	14.0	16.7	5.233	.3597	-0.444	.2865	.4935	2.468	.392
5/15 3:34PM	5v	1.0449	14.4	17.8	5.220	.3794	-0.421	.2985	.5235	2.618	.418
5/15 4:04PM	6v	1.3686	14.4	17.8	5.220	.4965	-0.304	.3329	.6125	3.062	.486
5/2 11:44AM	9	1.5644	14.0	17.7	5.221	.5684	-0.245	.3354	.6185	3.092	.490
5/2 12:25PM	10	2.1257	14.2	17.7	5.221	.7716	-0.113	.3723	.6200	3.600	.556
5/15 4:37PM	7v	2.1891	14.4	18.0	5.217	.7947	-0.100	.3915	.7748	3.874	.588

Table No. 4 (b).

Loss of Head in 6" Wood Pipe.

1 T.	2 No.	3 Dm.	4 C.	5 C.	6 c.	7 Hf.	8	9 Vw.	10 Q.	11 Vm.	12.
5/2/08 8:26PM	1h	0.047	14.2	17.8	5.220	.0172	-1.764	.0732	.0678	0.355	-.450
5/3/8 5:15	1v	0.055	13.0	18.1	5.216	.0201	-1.697	.0897	.0908	0.475	-.323
5/2/08 9:30PM	2h	0.198	14.4	18.0	5.217	.0720	-1.143	.1424	.1790	.936	-.029
5/7/8 8:55PM	2v	0.240	12.1	13.2	5.276	.0864	-1.063	.1525	.1980	1.036	-.015
5/2/8 10:11PM	3h	0.451	14.4	18.0	5.217	.1639	-0.785	.1978	.2890	1.511	.179
5/7/8 4:39PM	3v	0.521	12.1	12.9	5.279	.1872	-0.728	.2025	.2990	1.564	.194
5/2/8 4.25PM	4h	0.921	13.9	17.7	5.221	.3343	-0.476	.2480	.4015	2.101	.322
5/7/8 10:12PM	4v	0.991	12.1	13.0	5.278	.3560	-0.449	.2523	.4120	2.155	.333
5/3/8 2:46PM	5h	1.378	12.2	18.0	5.217	.5001	-0.301	.2933	.5100	2.668	.426
5/8/8 11:24AM	5v	1.397	12.2	13.3	5.274	.5000	-0.301	.2855	.4900	2.562	.409
5/3/8 3:25PM	6h	1.957	12.2	18.0	5.217	.7110	-0.148	.3303	.6055	3.167	.501
5/8/8 1:20PM	6v	2.091	12.1	12.8	5.280	.7510	-0.124	.3296	.604	3.162	.500
5/3/8 4:12PM	7h	2.477	12.3	18.1	5.216	.8990	-0.046	.3556	.6760	3.536	.549
5/8/8 3:00PM	7v	2.610	11.8	12.8	5.280	.9385	-0.028	.3591	.6840	3.580	.554

Table No. 4 (c).

Loss of Head in 6" Steel Pipe.

1	2	3	4	5	6	7	8	9	10	11	12
T	No.	Dm	C	C	c	Hf		Vw	Q	Vm	
5/1/8 8:23PM	1	0.059	14.1	16.6	5.234	.0199	-1.701	.0880	.0892	0.432	-.365
8:53 PM	2	0.119	14.1	16.6	5.234	.0401	-1.397	.1190	.1380	0.669	-.175
9:19PM	3	0.191	14.1	16.7	5.233	.0639	-1.194	.1438	.2450	0.883	-.054
9:46PM	4	0.321	14.1	16.7	5.233	.1076	-0.968	.1764	.2950	1.188	.075
10:16PM	5	0.455	14.2	16.7	5.233	.1526	-0.816	.2009	.3610	1.431	.156
10:42PM	6	0.664	14.2	16.7	5.233	.2227	-0.652	.2314	.4430	1.750	.243
5/2/8 8:32AM	7	0.990	14.0	16.7	5.233	.3321	-0.479	.2664	.5140	2.144	.331
8:55AM	8	1.308	14.0	16.7	5.233	.4383	-0.358	.2949	.5940	2.495	.397
9:25AM	9	1.700	14.0	16.8	5.232	.5700	-0.244	.3260	.5940	2.881	.460
9:53AM	10	2.301	14.0	16.8	5.232	.7712	-0.113	.3649	.7000	3.394	.531

Table No. 4 (d).

Loss of Head in 6" Lap Riveted Pipe.

1	2	3	4	5	6	7	8	9	10	11	12
T	No.	Dm	C	C	c	Hf		Vw	Q	Vm	
5/8/8 5:29PM	1v	0.091	12.1	15.4	5.249	.0328	-1.484	.0960	.1005	0.538	-.269
7:59	2v	0.231	12.4	17.5	5.223	.0839	-1.076	.1506	.1946	1.041	+.017
8:40	3v	0.503	12.4	18.4	5.212	.1829	-0.738	.2074	.3088	1.653	+.218
9:15	4v	0.815	12.4	18.4	5.212	.2963	-0.528	.2456	.3940	2.109	+.324
9:54	5v	1.488	12.4	18.7	5.209	.5410	-.267	.2919	.5050	2.702	+.432
10:34	6v	1.825	12.4	18.7	5.209	.6640	-0.178	.3349	.6175	3.305	+.519
	7v	2.533	12.4	18.8	5.208	.9210	-0.036	.3686	.7100	3.800	+.580
11:10											

follows: The average ordinate and abscissa was computed for all the points, and then the average ordinate and abscissa for all points above and below this center of gravity separately, which gave three points in a straight line. The lowest velocities for the cast iron, wood, and lap-riveted pipes were thrown out in this determination, because they were unreliable. The discrepancy in these points was probably due to leakage as at the lowest velocity there was considerable pressure on the pipes in order to keep them full, and maximum leakage with minimum flow would produce a noticeable shifting of the point on the curve.

Pitot Tubes. On pages 34 and 35 is given one traverse made on the vertical diameter of the steel pipe, which is a portion of Table No.6, (a), (b), (c) and (d), Laboratory Data, pages Nos. 70 to 127 inclusive. The traverse at the medium velocity is given. Column No. 6 gives the average difference of head, H_v, for each position. Column No. 9 contains H_v corrected for the no flow reading. Positions Nos. 1, 7 and 13 are at the center of the pipe, No. 2 at the far side and No. 12 the entry side of the pipe.

In reducing the difference of head observed, it was considered as velocity head and the velocity was calculated from $v = \sqrt{2 g h_v}$. The values of the velocities calculated for the different positions are given in column No.8. The center velocity, V_c and the mean velocity V_m is given at

Table No. 6 (c).

Pitot Tube Calibration. Traverse 4 V.

Data by Graff. May 21, 1908. Temp. Water 16.7 C.

No.	T. P.M.	Pos-it-ion.	Pitot Tube #1. V.	Pr.	Hv.	Hv + Cor. of -.005	V.
1.	2.	3.	4.	5.	6.	7.	8.
1	9:32	1	2.003	1.910			
2			1.964	1.848)			
3			1.998	1.915)			
4	9:33		1.960	1.852)	.100	.095	2.47
5	9:35½	2	1.980	1.825			
6			1.942	1.863)			
7			1.982	1.827)			
8	9:36½		1.945	1.874)	.068	.063	2.01
9	9:37	3	1.892	1.819			
10			1.956	1.859)			
11			1.990	1.905)			
12	9:38		1.960	1.856)	.090	.085	2.34
13	9:38½	4	2.003	1.905			
14			1.968	1.852)			
15			2.005	1.904)			
16	9:39½		2.964	1.842)	.106	.101	2.55
17	9:40	5	2.007	1.901			
18			1.962	1.850)			
19			1.997	1.890)			
20	9:41		1.967	1.840)	.112	.107	2.62
21	9:41½	6	2.012	1.903			
22			1.973	1.849)			
23			2.007	1.895)			
24	9:42		1.969	1.841)	.118	.113	2.70
25	9:42½	7	2.013	1.909			
26			1.972	1.841)			
27			2.009	1.900)			
28	9:44		2.069	1.949)	.116	.111	2.67
29	9:45	8	1.998	1.937			
30			1.956	1.878)			
31			1.988	1.941)			
32	9:45½		1.953	1.877)	.066	.061	1.98
33	9:46	9	1.981	1.951			
34			1.940	1.888)			
35			1.985	1.948)			
36	9:47		1.945	1.888)	.044	.039	1.58

Table No. 6(c) Continued.

1	2	3	4	5	6	7	8
37	9:47½	10	1.967	1.948			
38			1.928	1.891)			
39			1.960	1.949)	.026	.021	1.16
40	9:48½		1.927	1.890)			
41	9:49	11	1.968	1.937			
42			1.930	1.884)			
43			1.967	1.930)			
44	9:50		1.931	1.879)	.041	.036	1.52
45	9:50½	12	1.955	1.945			
46			1.920	1.891)			
47			1.959	1.950)			
48	9:51		1.923	1.896)	.019	.014	0.95
49	9:51½	13	2.009	1.905			
50			1.968	1.844)			
51			2.012	1.897)			
52	9:52½		1.970	1.842)	.118	.113	2.70

Vc = 2.63 Vm = 2.11

the bottom of each traverse, and are determined as follows: The value of V_c is obtained by taking the sum of the first and third positions there and twice that of the second, and dividing by four. The mean velocity is determined by the summation of half the extreme or side velocities, twice the center velocity as just obtained and the intermediate velocities all divided by the number of positions. The center velocity being observed at the beginning, middle and end of each traverse, has been used twice in computing the mean velocities to compensate for the deficiency occurring from the summation of the several velocities. The velocity distribution curve follows some curve instead of the series of straight lines connecting the observed velocities, which would make the integrated mean velocity of this curve somewhat in excess of the value obtained from the above summation if no correction was made. Messrs. Williams, Hubbell and Fenkell in the Detroit experiments calculated that by using the center velocity twice, a value of V_m is obtained about 0.6 to 1% higher than would be obtained by integrating the volume of revolution generated by the mean curve drawn through the observations when 21 positions are used.

On Plates Nos. 11 and 12 are plotted all the traverses taken, and these show fairly uniform variations in the velocity across the diameter of the pipe. The velocity observations are connected by straight lines, though

PLATE 11

CALIBRATION OF PITOT TUBES

FIG. 1

CAST-IRON PIPE — DIAMETER [illegible]
PITOT TUBE VERTICAL

Traverse No. 1v — May 5, 1908, 2.14 P.M. — Pitot Tube No. [illegible]
2v [illegible] 46 P.M.
[illegible] 2:31 P.M.
[illegible] 2.56
[illegible] 3.35
[illegible] 4.05
[illegible] 4.37
6v — May 2, 1908 11.36 A.M. — Pitot Tube [illegible]
7v — 12.25 P.M.

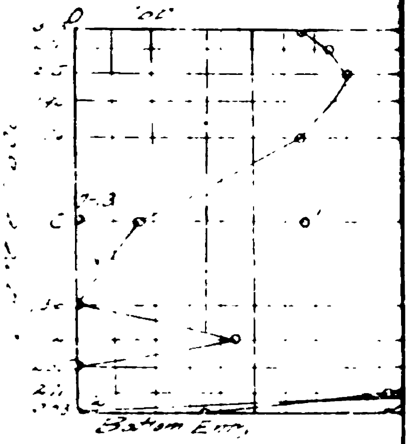


FIG. 2

CAST-IRON PIPE — DIAMETER [illegible]
PITOT TUBE HORIZONTAL

Traverse No. 1v — May 14, 1908, 8.37 P.M. — Pitot Tube No. 2
2v 9.23
3v 10.12
4v 10.33
5v [illegible]35
6v [illegible]
7v [illegible].40

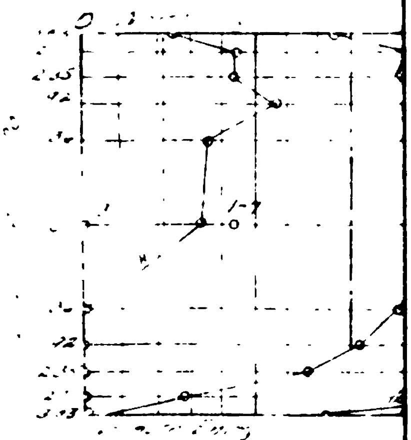


FIG. 3

[illegible]

Traverse No. 1v May 3, 1908, 5.15 [illegible]
2v [illegible]
3v 9.40
4v 10.13
5v [illegible]
6v [illegible]
7v [illegible]

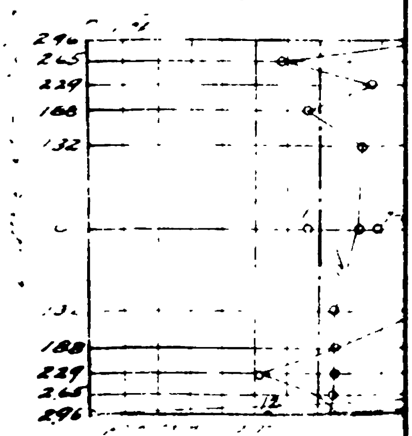
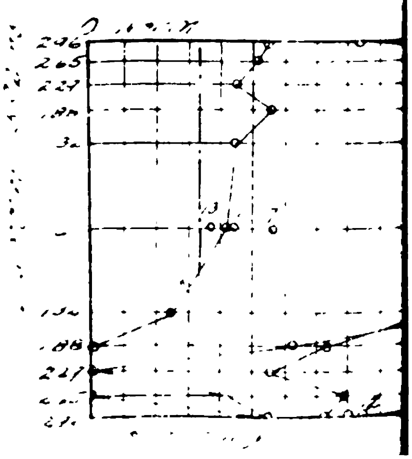


FIG. 4

WOOD PIPE — DIAMETER [illegible]
PITOT TUBE HORIZONTAL

Traverse No. [illegible] — May 2, 1908 8.43 P.M. — Pitot Tube No. [illegible]
2v 9.34
[illegible] 10.12
[illegible] 4.33
[illegible] May 3, 1908, 2.45
[illegible] 3.25
7v 4.[illegible]



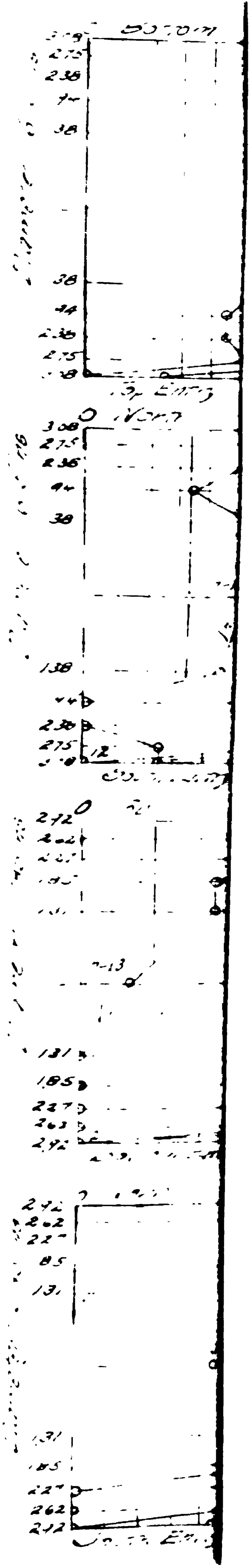


PLATE I[illegible]

CALIBRATION OF PI[illegible] TUBES

FIG 1

STEEL PIPE — DIAMETER, 6.15 in
[illegible] TUBE [illegible]

Traverse No 1v - May 21, 1908, 10:46 PM - Pitot Tube .
" " 2v - " " , " [illegible]25 " " - " "
" " 3v - " " , " , 1004 - " " - " "
" " 4v - " " , " , [illegible]42 " " - " "
" " 5v - " " , " , [illegible] " " - " "
" " 6v - " " , " , [illegible]42 " " - " "
" " 7v - " " , " , 8.12 " " - " "

FIG 2

STEEL PIPE - DIAMETER [illegible]
PITOT TUBE HORIZONTAL

Traverse No 1H - May 15, 1908, 8:33 PM - Pitot Tube [illegible]
" " 2H - " " , " , 9.09 " " - " "
" " 3H - " " , " , 9.31 " " - " "
" " 4H - " " , " , 10:01 " " - " "
" " 5H - " " , " , 10:18 " " - " "
" " 6H - " " , " , 10.48 " " - " "
" " 7H - " " , " , 11.09 " " - " "

FIG. 3

SPIRAL LAP-RIVETED [illegible] DIAM., 5.85 ins
PITOT [illegible]

Traverse No 1v - [illegible] 5:32 PM. Pitot Tube [illegible]
" 2v - " " " 7.57 " " " "
" 3v - " " " 8:38 " " - "
" " 4v - " 9:[illegible] " " " " "
" " 5v - " 9.5 " " - " " "
" " 6v - " " , 0:28 " " " "
" " 7v - " " , 1:04 " " - " " "

FIG. 4.

SPIRAL LAP-RIVETED PIPE - DIAM., 5.86 [illegible]
[illegible] TUBE HORIZONTAL

Traverse No 1H - May 9, 1908, 10:43 AM - Pitot Tube [illegible]
" " 2H - " " , " 11:24 " " - " "
" " 3H - " " , " 2:11 P.M. - " "
" " 4H - May 10, 1908, 9:16 A.M. - " "
" " 5H - " " , " 9.48 " " - " "
" " 6H - " " , " [illegible]20 " " - " "
" " 7H - " " , " [illegible]50 " " - " "

evidently actual conditions in the pipe are represented by a smooth curve. The three center velocities are shown, but the traverse is drawn through the average calculated center velocity.

Table No. 7, (a), (b), (c) and (d) is a summary of Table No. 6, (a), (b), (c) and (d), and contains the results of all traverses taken for the cast iron, wood, steel and lap-riveted pipes respectively. Columns Nos. 4 and 5 give the average center and mean velocities, and column No. 6 the true weir velocity V_w. Column No. 7 gives the ratio of V_w to V_c, V_c being the calculated center velocity. Column No. 8 contains the values of the coefficient, $c = \frac{V_w}{V_m}$. In computing the average value of the coefficient of each tube, those traverses marked with an asterisk were rejected as unreliable. All Pitot tube measurements for a velocity of less than 0.5 ft. per second are of no value in calibration and were rejected, because often negative readings are recorded and errors in reading have too large an effect on the small difference of head. Traverse No. 2 H of the cast iron pipe was eliminated for the reasons cited in the above; traverses Nos. 4 V and 5 V of the same pipe were thrown out since the guage was apparently not reading correctly, perhaps due to air in the tubing. An inspection of traverses Nos. 3 H, 6 H, 5 V and 6 V as plotted on Plate No. 11, Figs. Nos. 4 and 3 shows these to be erratic;

Table No. 7 (a).

Pitot Tube Calibration. Summary.

Tube No. 2 - 6" Cast Iron Pipe.

1	2	3	4	5	6	7	8	9
No. of Traverse.	Date.	Duration of Exp. Mins.	Velocity Ft./Sec. By tube at Ctr. Vc.	By tube Mean. Vm.	By Weir Mean Vw	Ratio. Vw/Vc.	Coefficient Vw/Vm. C.	Temp. of Water C. T.
1 H	5-14-08 8:37 PM	30.0	0.33	0.21	0.51	1.541	2.14	14.7
2 H	9:23	29.5	1.15	0.90	0.93	0.810	1.03	14.7
3 H	10:12	26.5	2.01	1.70	1.42	0.703	.83	14.7
4 H	10:33	25.0	2.82	2.35	1.97	0.699	.839	14.7
5 H	10:55	18.5	3.74	3.20	2.57	0.687	.80	14.7
6 H	11:18	15.5	4.35	3.67	3.01	0.692	.82	14.7
7 H	11:40	19.0	5.19	4.42	3.51	0.676	0.79	14.7
1 V	5-15-08 12:14 PM	17.5	0.17	0.38	0.47	2.800	1.250	14.4
2 V	11:46 AM	19.0	1.36	1.25	0.964	.709	0.772	14.4
3 V	2:31 PM	21.0	1.82	1.47	1.46	0.801	0.991	14.4
4 V	2:58	20.5	2.42	1.89	1.97	0.816	1.043	14.4
5 V	3:35	20.5	3.26	2.55	2.61	0.801	1.025	14.4
6 V	4:05	23.5	3.85	3.23	3.07	0.797	0.949	14.4
7 V	4:37	20.0	5.01	4.28	3.87	0.772	0.902	14.4

Table No. 7 (b).

Pitot Tube Calibration. Summary.

Tube No. 1 - 6" Wood Pipe.

1	2	3	4	5	6	7	8	9
No.	Date.	T.	Vc.	Vm.	Vw.	Vw/Vc.	C.	T.
1 H	5-2-08 8:43 PM	32.5	0.42	0.32	0.36	0.855	.973	13.9
2 H	9:30	32.0	1.37	1.11	0.94	0.687	.849	14.4
3 H	10:12	44.5	1.91	1.29	1.51	0.789	1.170	14.4
4 H	4:33	46.0	3.20	2.56	2.11	0.661	0.827	13.9
5 H	5-3-08 2:45 PM	27.5	3.97	3.10	2.67	0.671	0.861	12.2
6 H	3:25	36.0	4.30	3.24	3.17	0.737	0.980	12.2
7 H	4:13	29.0	5.44	4.45	3.54	0.650	0.797	12.3
1 V	5:15	30.0	0.83	0.78	0.475	.572	0.608	12.3
2 V	5-7-08 8:57 PM	30.0	1.67	1.28	1.04	0.623	0.813	12.1
3 V	9:40	27.5	2.47	2.02	1.56	0.630	0.772	12.1
4 V	10:13	28.5	3.30	2.71	2.16	0.655	0.798	12.1
5 V	3-8-08 11:21 AM	35.5	3.67	2.78	2.60	0.710	0.935	12.2
6 V	12:07 PM	24.0	4.25	3.00	3.162	0.744	1.059	12.1
7 V	3:00	32.0	5.47	4.53	3.58	0.654	0.791	12.1

Summary for 6" Cast Iron Pipe.

6 Va	5-2-08 11:45 AM	34.0	4.45	3.32	3.10	6.97	0.932	14.2
7 Va	12:25	32.5	5.22	3.89	3.60	6.89	0.927	14.2

Table No. 7 (c).

Pitot Tube Calibration. Summary .

Tube No. 1 - 6" Steel Pipe.

1 No.	2 Date.	3 T	4 Vc.	5 Vm.	6 Vw.	7 Vw/Vc	8 C.	9 T.
1 H	5-15-8. 8:33PM	0.52	0.39	0.53	1.020	1.358	14.7	29.0
2 H	9:09	1.18	0.92	0.92	0.780	1.000	14.7	15.5
3 H	9:31	1.82	1.47	1.36	0.750	0.930	14.7	16.5
4 H	10:01	2.62	2.15	1.91	0.729	0.889	14.7	13.0
5 H	10:18	3.59	2.93	2.54	0.708	0.868	14.7	24.5
6 H	10:48	4.21	3.47	3.00	0.712	0.867	14.7	17.0
7 H	11:09	4.92	4.07	3.47	0.705	0.853	14.7	20.5
1 V	5-21-8. 10:46	0.76	0.59	0.48	0.638	0.820	16.7	18.5
2 V	10:25	1.43	1.20	0.98	0.686	0.818	16.7	14.0
3 V	10:04	2.01	1.72	1.46	0.725	0.849	16.7	16.5
4 V	9:32	2.63	2.11	2.00	0.760	0.947	16.7	20.5
5 V	9:07	3.71	3.06	2.44	0.659	0.798	16.7	18.0
6 V	8:42	4.48	3.81	2.95	0.660	0.777	16.7	20.0
7 V	8:12	5.32	4.44	3.52	0.661	0.793	16.7	23.5

Table No. 7 (d).

Pitot Tube Calibration. Summary.

Tube No. 2 - 6" Lap-Riveted Pipe.

1	2	3	4	5	6	7	8	9
No.	Date.	T	Vc.	Vm.	Vw.	Vw/Vc	C.	T.
1 H	5-9-8. 10:43AM	0.72	0.62	0.55	0.763	0.821	13.4	35.0
2 H	11:29	1.39	1.06	1.08	0.777	1.020	13.4	32.5
3 H	12:11	2.08	1.67	1.58	0.759	0.946	13.4	26.5
4 H	5-10-8. 9:16AM	3.26	2.58	2.175	0.668	0.843	13.2	23.0
5 H	5-10-8. 9:48	3.93	3.23	2.665	0.679	0.825	13.2	19.5
6 H	10:20	4.46	3.62	3.185	0.713	0.880	13.2	22.5
7 H	10:50	5.16	4.19	3.82	0.739	0.912	13.2	24.0
1 V	5-8-8. 5:32PM	0.17	0.27	0.535	3.15	1.980	12.3	29.5
2 V	7:57	1.37	1.14	1.04	0.760	0.912	12.4	27.0
3 V	8:38	2.31	1.85	1.654	0.716	0.894	12.4	28.5
4 V	9:16	3.01	2.33	2.11	0.701	0.907	12.4	27.5
5 V	9:51	3.95	3.22	2.70	0.683	0.840	12.4	30.0
6 V	10:28	4.98	4.25	3.30	0.661	0.778	12.4	28.5
7 V	11:04	5.72	4.75	3.81	0.664	0.802	12.4	30.0

the same is true of No. 4 V for the steel pipe, Plate No. 12, Fig. No. 1. In Table No. 8 is given a summary of the co-efficients of Pitot tubes Nos. 1 and 2, as determined in the four pipes, and also the co-ordinates of the centers of gravity B, C and A of the points on Plate No. 13. All true weir velocities are plotted as ordinates and mean velocities as abscissae, but the traverses marked with the asterisk in Table No. 7 are not used in the calculation of the centers of gravity. A straight line is drawn through the centers of gravity for each tube.

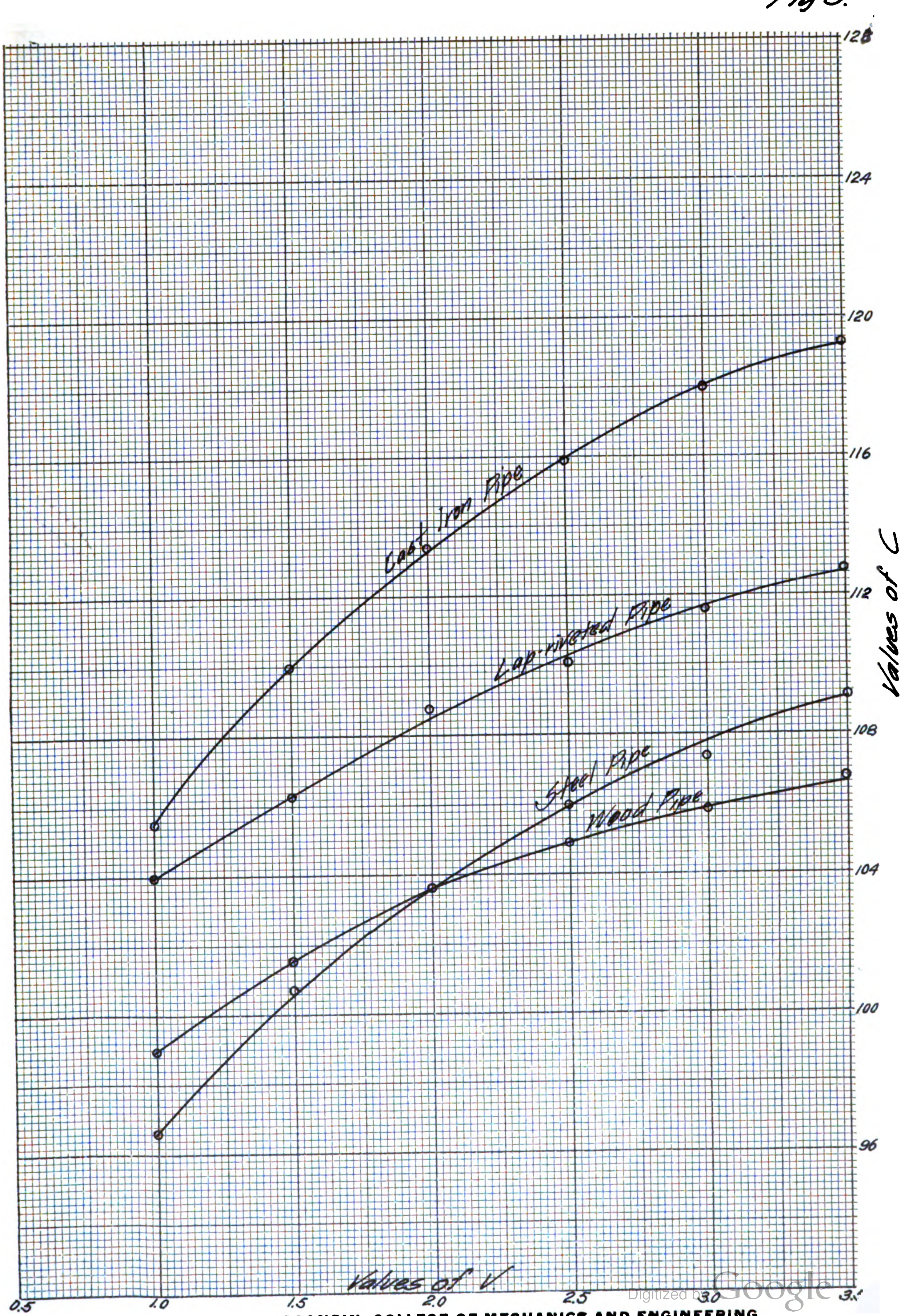
TABLE NO. 8.

Final Summary of Calibration of Pitot Tube.

Ins. & Pos.	Pipe	Arithmetic Means. V_w/V_c		$V_w/V_m = C$.		Co-ordinates of Points B, C and A. B V_m	B V_w	C V_m	C V_w	A V_m	A V_w
2 V	CI.	.769		.903	.860						
2 H	CI.	.683	.717	.816		1.733	1.545	2.684	2.219	3.832	3.228
2 V	LR.	.697		.856	.879						
2 H	LR.	.722		.903							
1 V	W.	.641		.806	.820						
1 H	W.	.667	.708	.834		1.714	1.446	2.832	2.427	3.762	3.078
1 V	S.	.694		.807	.854						
1 H	S.	.731		.901							

Final Average Coef. of Tube No. 1 = .837

Final Average Coef. of Tube No. 2 = .870



UNIVERSITY OF WISCONSIN, COLLEGE OF MECHANICS AND ENGINEERING

RESULTS.

Discharge Measurement. The 12-in. weir was also calibrated in 1907, and this calibration checked within less than 1% with that of Messrs. Cerna and Kaulfuss in 1908. The errors in the measurements of discharge are negligible. The percentage of error in the velocities as determined from the diameters is not more than 1%.

Frictional Losses. The relation between frictional loss of head and velocity is plotted logarithmically in Figs. Nos. 1 to 4 inclusive for all the pipes, and the straight line obtained in each case shows that H_f varies with some power of the velocity, or $H_f = Mv^n$. Therefore Log. $H_f = n \log V + \log. m$. The value of n is obtained directly from the slppe of each curve, and m is obtained by taking the intercept for V = 1. The value of n and m as obtained for the four positions are given in Table No. 9.

Table No. 9.
Frictional Losses and Values of Coefficient.

Pipe	$H_f = mV^n$		H_f in ft. of water per 1000' and value of C in Chezy's Formula $V = C\sqrt{rs}$.							
	m for h_f in ft. of water per 1000'	n	1 ft/ sec.		2 ft/sec.		3 ft./sec.		3.5 ft/sec.	
			H_f	C.	H_f	C.	H_f	C.	H_f	C.
CI.	.711	1.797	.711	105.5	2.471	113.4	5.117	118.0	6.809	119.2
W.	.824	1.880	.824	99.0	3.030	103.6	6.501	105.9	8.710	106.8
S.	.832	1.808	.832	96.6	2.910	103.6	6.067	107.4	8.000	109.1
L.R.	.760	1.870	.760	104.0	2.779	108.8	5.927	111.6	7.912	112.7

The equations for the four pipes are:

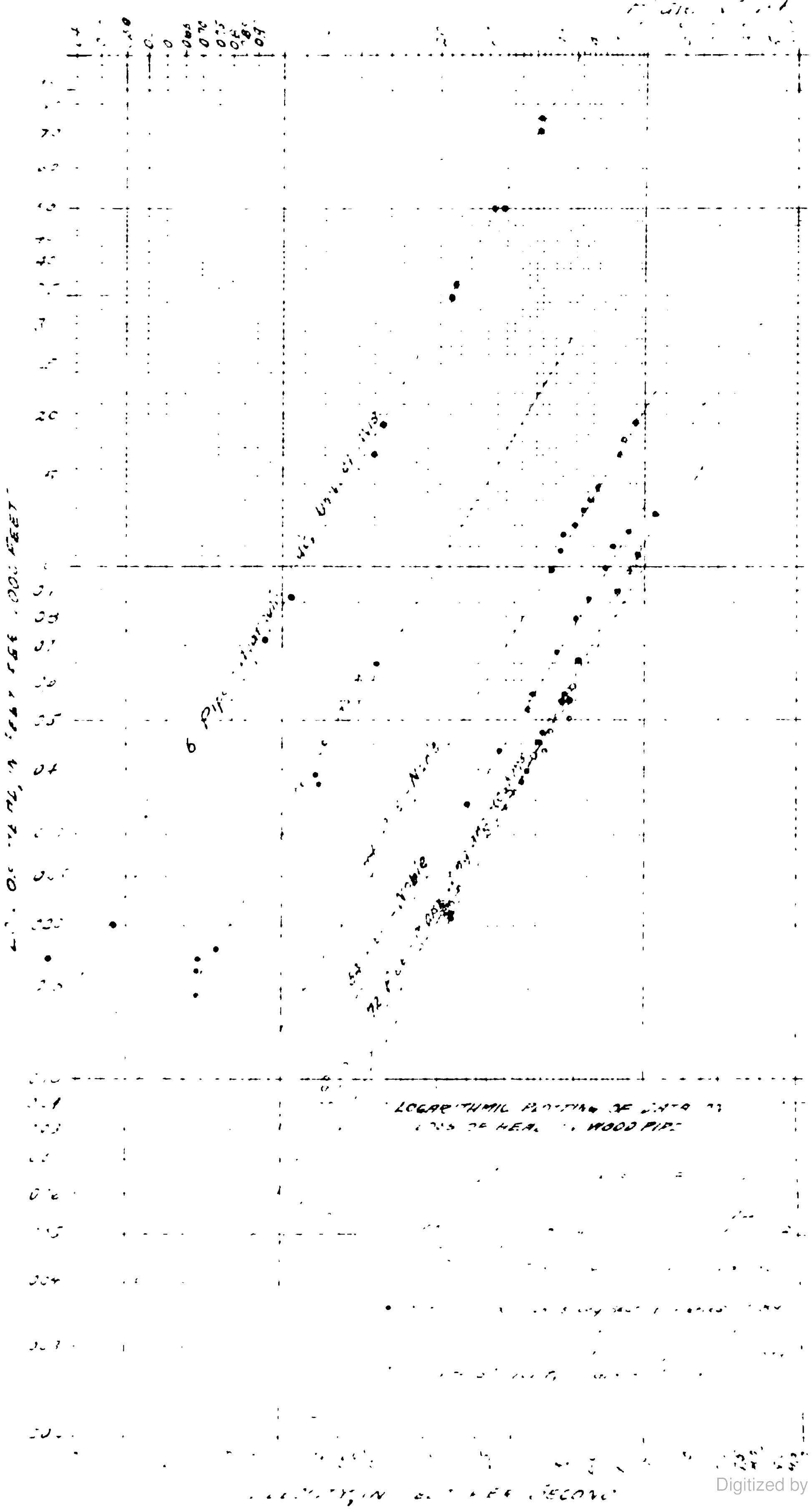
5.92 in. Wood pipe H_f per 1000 ft. = 0.824 $V^{1.88}$

6.06 in. Cast Iron pipe H_f per 1000 ft. = 0.711 $V^{1.80}$

6.15 in. Steel pipe H_f per 1000 ft. = 0.832 $V^{1.81}$

5.85 in. Lap-riveted pipe H_f per 1000 ft. = 0.760 $V^{1.87}$

On Plate XIV are plotted all the experiments hitherto made on wood pipes, most of which are of large diameter and all of which are wood stave pipes, except the 6-in. pipe tested by the writers. Uniformity in the slope of almost all these straight line curves is striking. The results of the experiments in 1899 on the 72-in. pipe by Marx, Wing and Hoskins show a peculiar change from those of 1897. The dashed line represents an average of the points determined in 1897, and the dotted line that of the experiments of 1899. The irregular distribution of the points of the former makes only an approximation of the slope possible. The experiments of 1899 give a much better line, the slope of which is L.94 instead of L.73 for the 1897 experiments. The cause of this increase in the slope in two years' service of the large stave pipe is hard to explain, unless it should be deterioration of the pipe in that time due to growths in the pipe. The equations of all the pipes plotted in Plate No. XIV are:



LOGARITHMIC
WOOD PIPE

5.92 in.	H_f per 1000 ft.	$= 0.824\ V^{1.88}$
14.05 in.	" " " "	$= 0.30\ V^{1.73}$
44.05 in.	" " " "	$= 0.125\ V^{1.73}$
54.2 in.	" " " "	$= 0.082\ V^{1.73}$
72.5 in.(1897)	" " " "	$= 0.062\ V^{1.73}$
72.5 in.(1899)	" " " "	$= 0.048\ V^{1.94}$

On examining these equations one is at once impressed by the constant value of 1.73 for n secured by Adams and by Noble on their experiments on the 14-in. and on 44 and 54-in. pipes respectively. This value is also secured by Marx, Wing and Hoskins, experiments of 1897. But the fine line of the 1899 experiments on the same pipe, which the latter obtained two years later would incline one to the conclusion that 1.94 represents the more correct value of n. for the 72-in. pipe in actual use, with a possibility that the increase in the value of n is due to growths on the inner surface of the pipe. The value of 1.88 secured by the writers for the 6-in. pipe checks the higher value of the 72-in. pipe. It must, however, be borne in mind in making the comparison that the 6-in. pipe is a bored pipe and probably has a somewhat rougher innersurface than a good stave pipe. The relative condition too of any two stave pipes would undoubtedly affect the value of n.

That the condition of the inside of the pipe has some

effect on the slope seems to be shown by the relative values of n obtained for the wood, cast iron, steel and lap-riveted pipes. In the smooth tar-dipped cast iron pipe, the value of n is 1.80 and the steel pipe has only a slightly greater n, 1.81. The lap-riveted pipe on the other hand shows a decided increase in the n. This may be expected because of the interference of the rivets with the flow. The value would probably have been higher if the steel pipe instead of being very smoothly surfaced, had been rough as most pipes in actual service are. The resistance of the 6-in. spiral lap-riveted pipe is very probably less than a similar pipe made with cylinder joints.

The variations of m in the wood pipes are seen at a glance at the equations to be uniform, and evidently to be a function of the diameter. On Plate No. XV are plotted logarithmically the value of m as ordinates and the diameters of the pipes as abscissae for all the wood pipes given in Plate No. XIV. By the center of gravity method the straight line was drawn, and the points are seen to lie very close to this line. The equation of the line is $m = \frac{k}{D^{1.07}}$, in which k is found to be .392, giving $m = \frac{.392}{D^{1.07}}$. k is taken off the curve for D = 1 ft. The 44-in. pipe is the only one that is materially off the line. In his discussion of paper No. 938 of "Transactions American Society

of Civil Engineers,"Volume 49, Mr. E. W. Schodder deduces a value for the exponent of D of 1.05 by taking all of the wood experiments up to date. By using these same data and the results obtained for the 6-in. bored wood pipe, the slope of the line is made 1.07 a change of only 2%, and the point for the 6-in. pipe lies almost exactly on the line so obtained. This evidence would indicate that the value of 1.07 is very nearly correct. In the experiments on the 44-in. pipe a range of velocity of from 3.5 to 5 ft. per second was the maximum that could be obtained, and this small range may or may not have had some effect upon the values of m and n. By neglecting the 44-in. pipe from the calculations the curve would have the position indicated by the dashed line, and the equation of the line becomes

$$m = \frac{.371}{D^{1.034}}.$$

The values of m for the cast iron, steel and lap-riveted pipes are also shown on Plate No. XIV, and they also lie very close to the straight line, which would seem to indicate that the value of m is independent of the condition of the pipe and dependent only upon the diameter. In Table No. 9 are given the values of m and n for the four pipes, and the values of H_f and c in Chezy's formula $v = c\sqrt{r\ s}$ for velocities from 1 ft. to 3.5 ft. per second. In Fig. No. 5 the values of c and the velocities are plotted. By a study of Table No. 9 and this diagram

one can see the increasing effect of a high value of n upon H_f and c as the velocity increases. Also the change in values of m effect c and H_f more than changes in n for the lower velocities. Take for instance the wood and steel pipes with almost identical values of m, the c curves cross at 2 ft. per second due to the increasing effect of the high value of n for the wood pipe. The lap-riveted pipe has a relatively higher c for the low velocities than for the higher velocities. The frictional losses are the least in the cast iron and greatest in the wood pipe; the spiral lap-riveted pipe shows a coefficient, c, only a little below the cast iron, and the c for the steel pipe is only a little higher than that of the wood pipe. Despite the high value of n obtained for the lap-riveted pipe, its low value of m gives it a small frictional lossand a high coefficient.

Pitot Tube Calibrations. On Plates Nos. XI and XII are given all the traverses made in the calibrations of the Pitot tubes. These traverses all show a maximum velocity at or near the center of the pipe. In a number of the traverses the velocities at the center and .2 diameter from the center are the same indicating a point of maximum velocity somewhere between the two readings. The irregularities noticed especially in traverses Nos. 2 V, 5 V and 6 V Figs. No. 3 and 3 H of Fig. No. 4, Plate No. XI about .1 of a diameter from the sides of the pipe show a

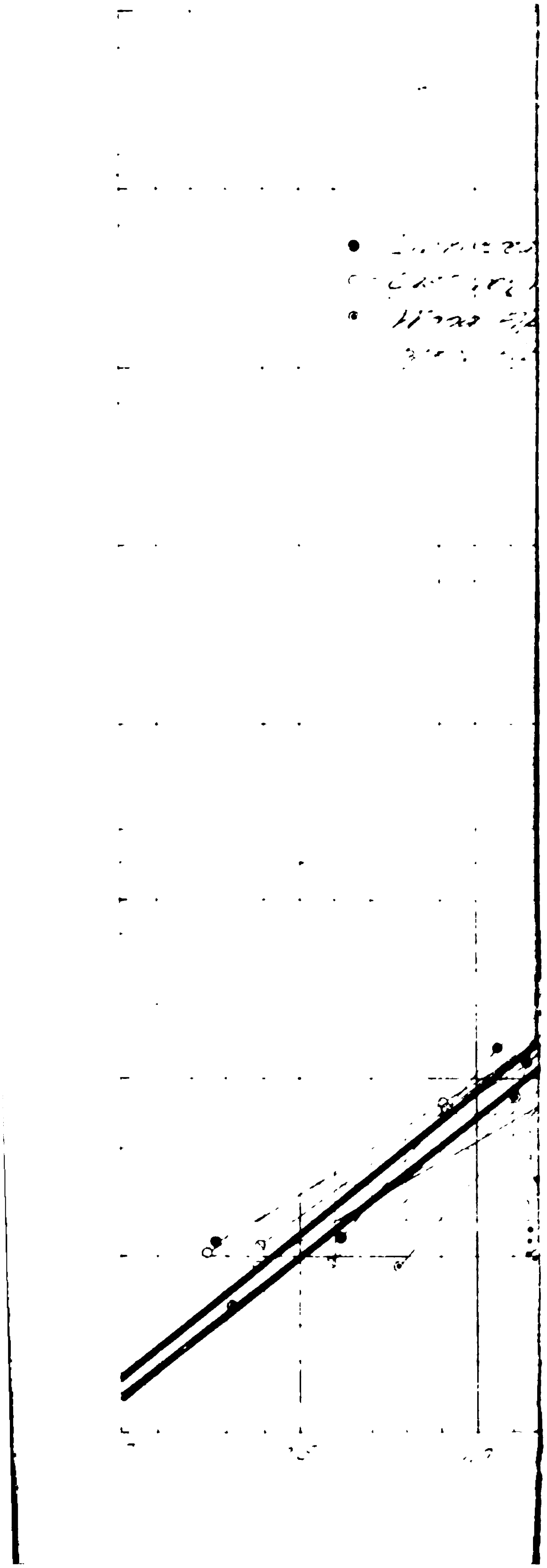
disturbance in the velocity distribution at these points. This is also especially noticeable in 3 V and 4 V, Fig. No. 1, Plate No. XII. The curves all show that the entry side has lower velocities than the opposite side. This may be due to the effect of the opening and water pocket created by the nipple. These high velocities however were also in every case on the same side of the pipe as the convex surface of the elbow or tee above the Pitot tube.

There can be no doubt but that these sharp 90° curves by which the water flowed had a marked effect upon the traverses. Those traverses having the maximum velocity above or below the center clearly show the disturbing effect of the curvature upon the velocity distribution. Williams, Hubbell and Fenkell found that the effect of curvature was noticeable in the velocity distribution several hundred feet below the curve, but they also showed by a large number of tests that the maximum distortion occurred in the first 90° of a 180° bend. It is not improbable that when the water passes by several 90° elbows in rapid succession, the disturbances due to one elbow may be counteracted by the effect of the next, especially when they are in opposite directions as was the case in the writer's experiments.

It was found that if a Pitot tube when indicating a high positive velocity where turned through an angle of 45° with the current, it would register zero, and a maximum

negative reading was obtained with the tube at 90° to the current. A number of zero and negative readings were recorded during the experiments, especially for the low velocities. The negative readings must have been due to eddy currents, probably caused by curvatures, as the above experiment would indicate, and for this reason all negative readings were considered as zero. The traverses on the whole show less abnormal distribution than would be expected from the irregular traverses obtained 20 or 30 ft. below curves of different radii in the Detroit experiments.

In Table No. 8 is given a summary of the coefficients found in each pipe for tubes Nos. 1 and 2, and also the ratio of true mean velocity, V_w to centre velocity V_c. Coordinates of points B, C and A on Plate No. XIII for each tube are also given. The coefficient for tube No. 2 in the cast iron pipe is .86 and in the lap-riveted pipe .879, which gives a difference of 2.2% in the two calibrations. The coefficient of tube No. 1 in the wood pipe is .820 and in the steel pipe .854, or a difference of 4%. The average coefficient of tube No. 1 is .837 and of tube No. 2 .870. A difference in the coefficients of the two tubes is to be expected. Although the tubes are made as nearly alike as a mechanician can make them, still slight differences in the construction would affect the coefficient. These tubes were



modeled after tube No. 5 used by Williams, Hubbell and Fenkell, the mechanician using as his working drawing the diagram of this tube on Plate No. I in the "Report of the Detroit Experiments." It is an especially interesting fact that tube No. 5 was the one which had perhaps the most uncertain coefficient of the types of tubes tested by Messrs. Williams, Hubbell and Fenkell. They first came to the conclusion that the coefficient of tube No. 5 was .86 from the tank rating in still water which made it .859 and their direct calibration in a 2-in. brass pipe, which made the coefficient .861. However, because of irregular distribution of velocities in the pipe rating and because the tank ratings for all the tubes were always from 4 to 10% higher than the pipe rating, they rejected the value of .86 for tube No. 5, and adopted as its coefficient .75. This value was obtained by a great many comparisons of tube No. 5 with tube No. 3 whose coefficient had been accurately determined. Tube No. 3 was inserted in a large main and many centre velocity readings taken simultaneously with piezometer readings for a considerable section of pipe. Tube No. 5 was then inserted and similar readings taken. By reducing these readings, the ratio of tube No. 3 to tube No. 5 was determined, and the above coefficient of .75 arrived at. Comparing the coefficients of tubes Nos. 1 and 2 found by the writers with that of tube No. 5 in the above, it is seen

that the value .837 of tube No. 1 is 2.7% lower than the rejected coefficient .86 of tube No. 5, while the value .87 for tube No. 2 is 1.2% higher than said coefficient.

Comparing the values of true mean velocity V_w to centre velocity V_c we find that $\frac{V_w}{V_c}$ for tube No. 1 is .708 and for tube No. 2 .717, a difference of 1.5%. The ratio obtained by Messrs. Williams, Hubbell and Fenkell was .694. Tube No. 1 has a ratio 2% and tube No. 2 a ratio 3.3% higher than this value. No centre velocity ratings were taken by the writers, the center velocities being the averages of the traverse readings. By taking a set of centre velocities alone, a more accurate check on the above value would be obtained.

It seems very unlikely that any possible difference in construction would account for the discrepancy betweenthe c_y .75 of tube No. 5 and the coefficients .837 and .870 of tubes Nos. 1 and 2. The further fact that Messrs. Williams, Hubbell and Fenkell first determined on .86 for the coefficient of No. 5, substantiates the above values. It is also possible that the conditions in a 6-in. pipe are much more similar to those in a tank rating than those in a small 2-in. pipe, and that the pipe ratings would not show such a discrepancy with tank rating if the Pitot tubes were calibrated in pipes of at least 6-in. or even larger diameter.

CONCLUSIONS.

Pitot Tube Calibrations. In order to secure more accurate calibrations of Pitot tubes in the pipes used by the writers, it is necessary to eliminate the effects of curvature by some means. A baffle plate perforated with small holes and situated just beyond the elbow fitting and then an enlargement chamber from which the water would pass through a cycloid-shaped reducer into the 6-in. pipe, would very likely give the necessary normal distribution of the velocity over the whole cross section. Another method would be the use of a Pitot tube, so made with velocity and pressure openings across the entire diameter of the pipe, that the tube would intergrate the mean velocity on the air guage. In this way fluctuations in the velocity across the diameter would not introduce errors into the traverse, as is the case when each traverse requires ten to twenty minutes. Of ccurse the difficulty of making a tube of this kind that would not interfere with the flow might make this method unfeasible.

A method of increasing the accuracy of low velocity readings and making low measurements of discharge possible is the use of a differential oil guage for reading with the Pitot tube. Unfortunately lack of time prevented the writers from making experiments with the use of the oil guage in addition to the calibrations that were made.

The coefficients determined were: tube No. 1, .837 and tube No. 2, .870. These coefficients are 2.7% lower and 1.2% higher respectively than the coefficient .86, determined from a similar rating of tube No. 5 (identical in design to the two tubes used by the writers) by Williams, Hubbell and Fenkell in the Detroit experiments.

Frictional Losses. The coefficients for the kerosene oil used in the differential oil guage was found to be 5.233 at 16.7° C. The frictional loss of head, H_v, does not vary with the square of the velocity. The values of m and n in the equation $H_f = m\,v^n$ were determined for cast iron, wood, steel and spiral lap-riveted pipes, and the following results were found:

6-in. Cast iron pipe	$H_f = 0.711\ V^{1.80}$
6-in. Wood pipe	$H_f = .824\ V^{1.88}$
6-in. Steel pipe	$H_f = .832\ V^{1.81}$
6-in. Spiral lap-riveted pipe	$H_f = 0.760\ V^{1.87}$

The order of resistance to flow in the pipes beginning with the least was as follows: cast iron, spiral lap-riveted, steel and wood. It must be borne in mind that all pipes were new. The experimental coefficients, c, in Chezy's formula obtained for the four pipes are as follows:

Pipe	Velocity in feet per Second.					
	1	1.5	2.0	2.5	3.0	3.5
Cast iron	105.5	110.0	113.4	115.9	118.0	119.2
Wood	99.0	101.6	103.6	104.9	105.9	106.8
Steel	96.6	100.8	103.6	106.0	107.4	109.1
Lap-riveted	104.0	106.3	108.8	110.1	111.6	112.7

From Plate No. XV it was found that for wood pipe m varies with $\frac{1}{D^{1.07}}$ and the equation for m is $m = \frac{.392}{D^{1.07}}$

Accuracy of Results. The experiments were made in the hydraulic laboratory with every facility at the writers' command, and no pains were spared to secure good results. The errors in the determination of frictional losses are within 1% of correctness. In the Pitot tube measurement of discharge the accuracy is limited by the uniformity of flow, and the coefficients of the tubes are within 3% of correctness.

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